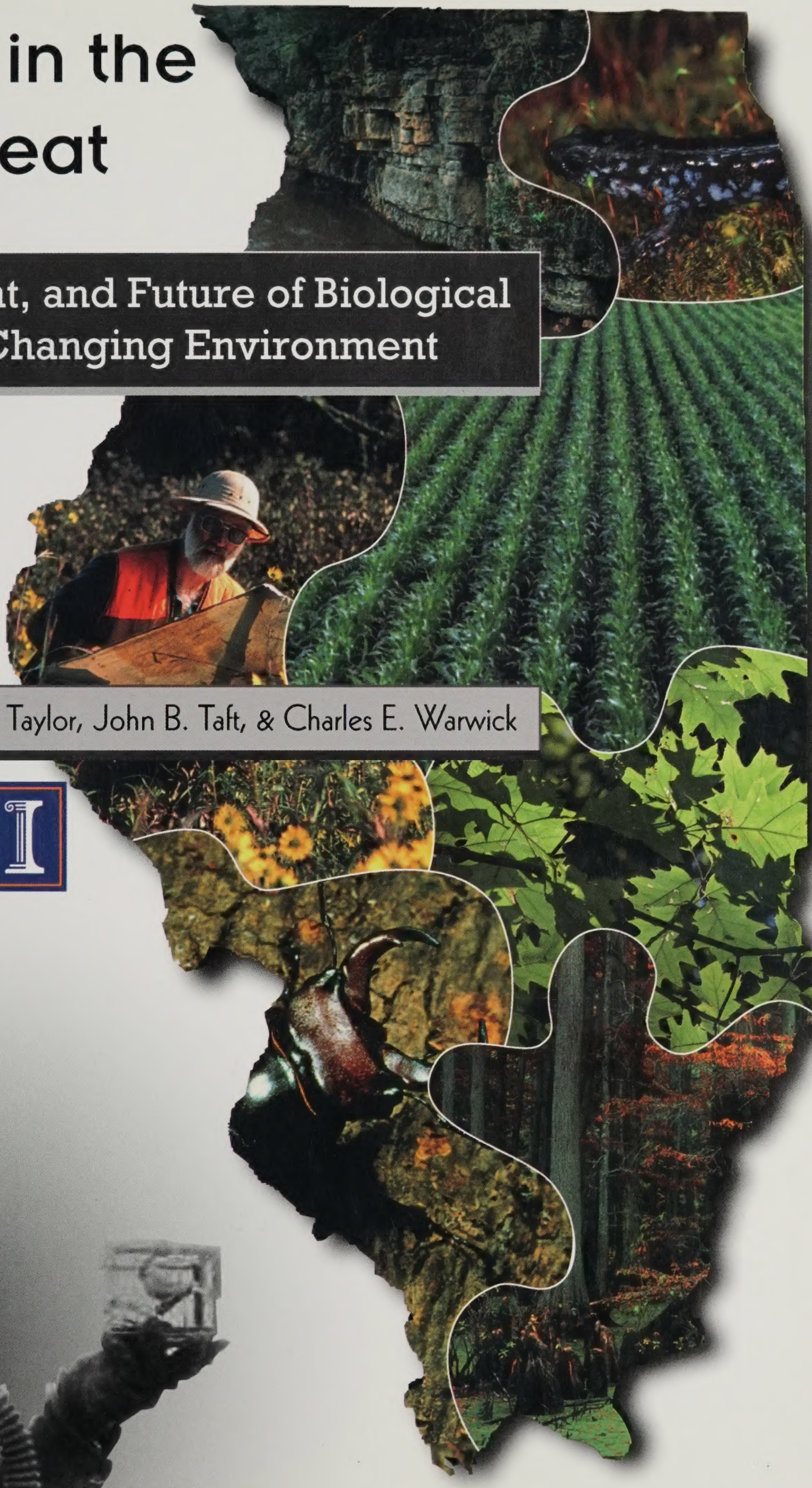
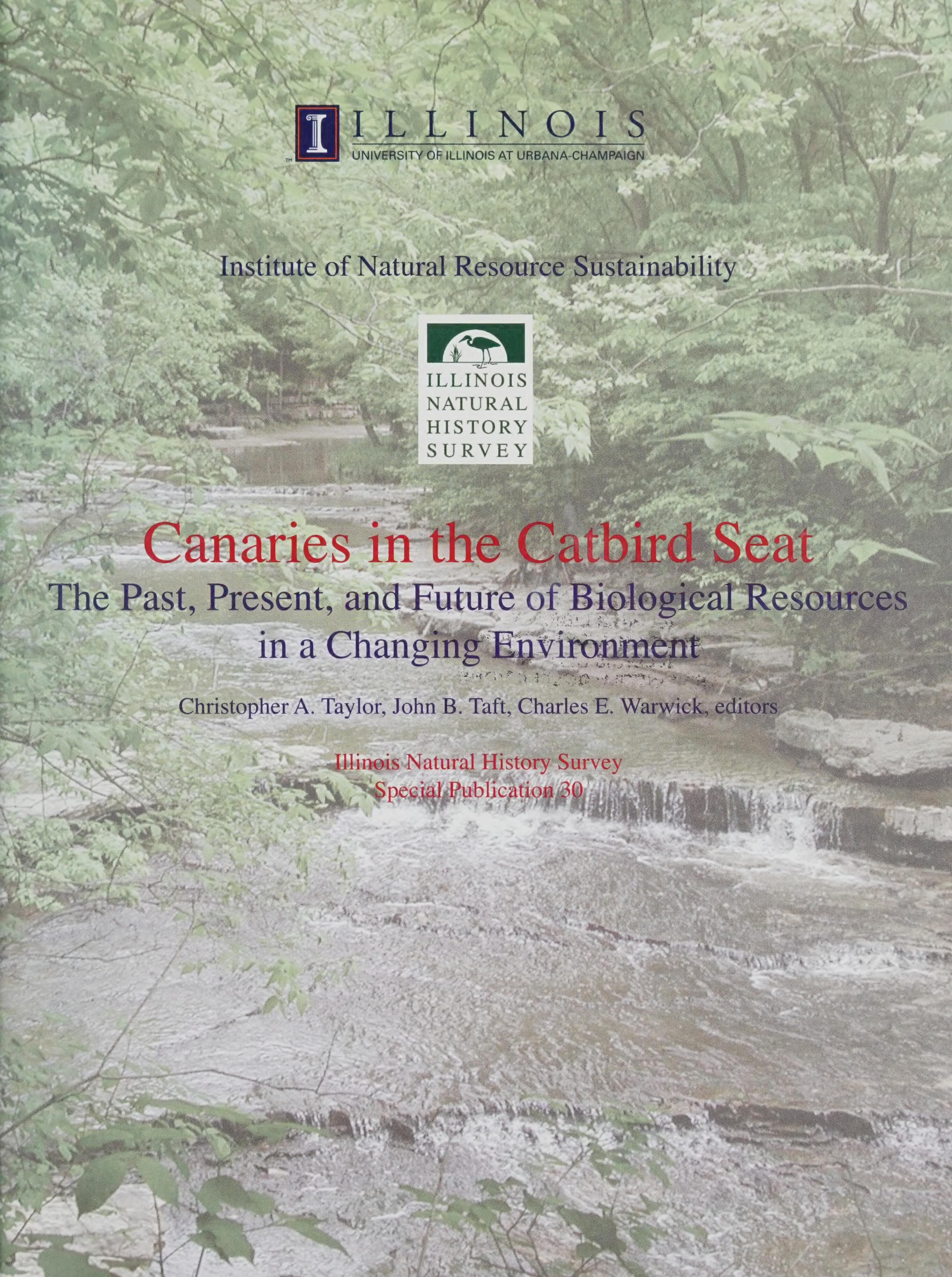
Canaries in the Catbird Seat

The Past, Present, and Future of Biological Resources in a Changing Environment



Edited By: Christopher A. Taylor, John B. Taft, & Charles E. Warwick

150 years ILLINOIS NATURAL HISTORY SURVEY 1858 to 2008



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

Institute of Natural Resource Sustainability

ILLINOIS NATURAL HISTORY SURVEY

Canaries in the Catbird Seat

The Past, Present, and Future of Biological Resources in a Changing Environment

Christopher A. Taylor, John B. Taft, Charles E. Warwick, editors

Illinois Natural History Survey
Special Publication 30

ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

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FOREWORD

Canaries in the Catbird Seat, the leading title phrase of this volume, in contrast to possible first impressions, is not a reference to biological phenomena such as nest parasitism or conflicts between native and non-native species. Rather, we use this title as a mixed metaphor to reflect the role of scientists and biologists who serve as environmental sensors through observation and research, much like the historic role of the mineshaft canary in alerting miners to the impending danger of low oxygen levels or poisonous gases. The Catbird Seat is a colloquialism coined by famed author and cartoonist James Thurber referring to a perch with a good view or being in an enviable position. We've applied this colloquialism to institutions and scientists involved in biological monitoring and research because of the benefit of perspective gained by extensive experience across many ecosystems and species groups. In this way, *Canaries in the Catbird Seat* applies particularly well to the Illinois Natural History Survey and its staff, who, since 1858, have had the unique and privileged position to make observations and analyze data collected throughout Illinois, the Midwest, and beyond.

The 150 year time span of these studies is perhaps unparalleled for biological monitoring agencies in the United States. In celebration of its 150th anniversary, these observations are summarized and recounted in the chapters of this volume in a language we hope is accessible to the broad audience of citizens interested in our shared natural heritage and in context with the wider scientific community. Curious readers will discover that many references cited herein reflect the varied contributions of Survey scientists over its 150 year history. However, our intent with this volume also is to reflect the integration of INHS by stressing not only the work done by Survey scientists but also the important relevant work done by external colleagues and other scientists and biologists. Two overarching themes generally resonate throughout the book. First is that humankind has caused dramatic changes to ecosystems in Illinois and beyond. Second is that sound science provided by biologists working at institutions such as INHS can be used to facilitate the recovery, wise use, and sustainability of our shared natural resources.

The Northern Starhead Topminnow (*Fundulus dispar*), a fish found sporadically in backwater habitats of Illinois. This painting first appeared in the 1908 publication *Fishes of Illinois (Volume III)* by Illinois Natural History Survey scientists Stephen A, Forbes and Robert E. Richardson. Paintings in this book were created by Lydia Hart and Charlotte Pinkerton.

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CONTENTS

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DEDICATION

The volume is dedicated to the scientists, past and present, who have contributed to the great volume of data on the biota of Illinois and to the citizens of Illinois. It is our hope that this volume contributes, at least in a small way, to inculcating a lasting appreciation of our shared natural heritage and an understanding of the need to protect and manage those resources so that functioning ecosystems teaming with life will continue to be a part of the Illinois landscape.

CHAPTER 1

Canaries in the Catbird Seat: An Introduction

Michael Jeffords, Charles Warwick, and Kenneth Robertson
Illinois Natural History Survey

INTRODUCTION AND OVERVIEW

Would that we could learn to appreciate the many things written with nature's pen. No rational human would think of ripping pages from a sacred book, but the human race is ripping not just pages, but entire chapters from the sacred world. Every time a species is lost, every time a plot of ground is paved, every time an oil spill occurs, irreplaceable messages — call them environmental indicators, if you must — are ripped from the pages of time.

James A. Tucker (pers. comm. to M. Jeffords, 1991)

The creation of *Canaries in the Catbird Seat* has been a daunting task, but one embraced at this moment in the history of the Illinois Natural History Survey, its 150th anniversary. For many chapters, large amounts of data were analyzed and synthesized to come to meaningful and scientifically valid conclusions. Individual authors surveyed substantial amounts of technical literature that underlie and support their various chapters. And finally, attempting to meld the sometimes disparate writing styles of multiple authors, yet still maintain a cohesive, readable style that reaches a relatively wide audience, is always a challenge. But like someone perched in a proverbial catbird seat, we at the Illinois Natural History Survey feel we have a unique perspective and are appropriately placed in time to attempt this difficult project, on this, our 150th Anniversary of existence.

With the exception of Chapter 2, which provides a vivid overview of the Illinois landscape, the remaining chapters are organized under two general themes. The first theme centers on change that has occurred since INHS' founding. Types of change include those to habitats, flora or fauna, or even management practices. The second theme is one of putting science to work. Chapters in this section demonstrate how much of the data discussed and compiled in the proceeding section can be used for such things as predicting future trends or improving habitat for declining plants and animals. Finally, a concluding chapter looks to what the future holds for natural resources in Illinois and beyond.

From its humble origin as a small group of educators and amateur naturalists in 1858, the Illinois Natural History Survey (INHS) has evolved into a preeminent state biological survey with the most complete collection of Illinois plant and animal specimens of any institution in the world. Now, a century and a half after its birth as the Illinois Natural History Society, INHS continues to serve the original mandate to create a comprehensive survey of the state's biological resources, to maintain a representative collection of plants and animals for education and research, to conduct research on a variety of topics relevant to the citizens of Illinois and the United States, and to disseminate new knowledge to the public.

Much like the organisms in the natural world that it studies, the survey has metamorphosed in several stages from a small cadre of unpaid volunteers to a large organization with more than 200 professional researchers and support staff. It is comprised of nine field stations throughout the state and several research and administrative buildings at the University of Illinois. In fact, in 2008, the Survey became part of the University of Illinois, housed in the Institute of Natural Resource Sustainability.

The survey has, through most of its history, had its biological collections serve as the focus for a significant portion of its research. The INHS Collections, forming the "biological memory" of the state, contain more than 8 million plant and animal specimens supported by more than 450 ongoing research projects such as descriptions of species new to science or examining how levels of toxic chemicals have changed over time in our streams. Without these collections and the immense amount of data they contain, much of the basic and applied research at INHS would not be possible.

Over the years, INHS has been housed in various agencies within state government, and has had to fight for its funding (along with every other agency) to maintain its programs and status as a world-class research institution. While the survey has seldom thrived financially, it has always risen to the challenge intellectually and the total number of INHS technical publications is nearing the 8,000 mark (Figs. 1.1 and 1.2). In 2007 alone, INHS scientists generated some 170 peer-reviewed papers published in scientific journals, 225 technical reports to contracting agencies, and many news articles, book chapters, Internet pages, book reviews, posters, and pamphlets. The public was also kept up-to-date with current research through hundreds of presentations by our scientists to schools, colleges, museums, private interest groups, and government agencies.

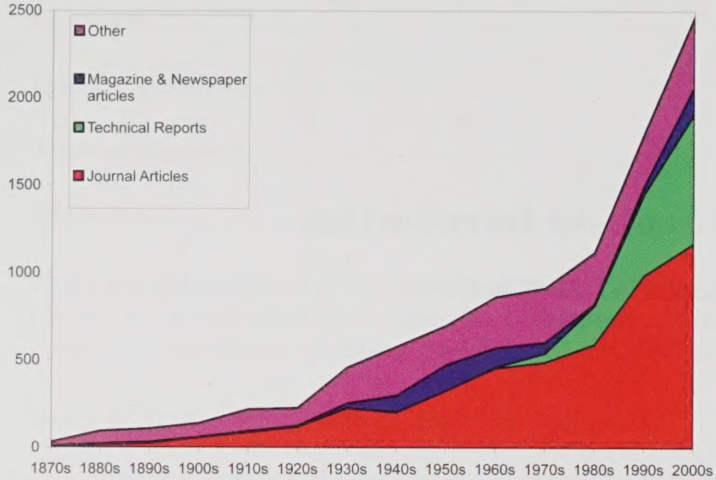

Figure 1.1. INHS staff publications by type of work and decade. Shown are journal articles, technical reports, and popular articles. "Other" = books, chapters, conference abstracts and proceedings. The bibliography on which the graph is based includes peer reviewed and popular articles, books, chapters, conference abstracts and proceedings, Web sites, and a small number of items written about staff (e.g., obituaries, encyclopedia entries). Graph compiled by S. Braxton.

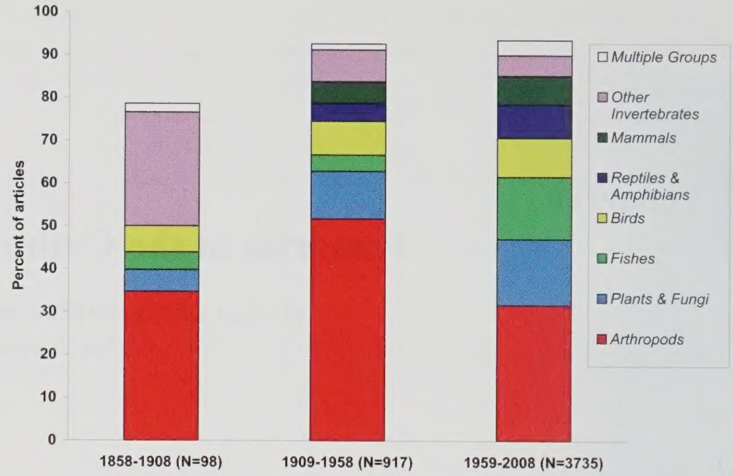

Figure1.2. Percentage of INHS staff authored journal articles by major taxonomic group during the first, second, and third half-centuries of INHS' existence. Only research and review articles are included. INHS in-house publications (i.e., INHS Bulletin and INHS Biological Notes) are excluded from the analysis. Graph compiled by S. Braxton.

SURVEY FORMATION

Naturally, an organization that can cast its net so widely did not spring into existence fully formed. Creating the Illinois Natural History Survey took imagination, foresight, some luck, and not a little effort and time.

Entomologist Cyrus Thomas of Carbondale was the first to propose a "state natural history society." He planted this seed in 1857 at the State Teachers Association annual meeting in Decatur (1). His timing must have been good because on June 30 of the next year (1858) a meeting was convened at the Illinois State Normal University (now Illinois State University; Fig. 1.3.) to form a natural history society. Meeting participants adopted a constitution which specified dues, membership requirements, and the society's officers including president, nine vice presidents, treasurer, secretary, librarian, and museum curator. The secretary was given charge of collecting and exchanging specimens, which were to be placed in the museum at the State Normal University.

By 1861 the state authorized the natural history society to establish its own museum at the university (1). In other words, ownership of the museum at the university was transferred to the natural history society. The society's charter stated that its purpose was "a scientific survey of the state of Illinois" as well as the creation of a library of scientific publications.

The society struggled to complete a comprehensive survey of Illinois' plants and animals. Without financial support from the state, the society's efforts were undertaken almost exclusively by unpaid volunteers. Consistency in the organization and maintenance of the collections was a chronic problem at the museum because no one person was employed to care for them. At the society's 1866 annual meeting, professor (and soon to be renowned explorer) John Wesley Powell (Fig. 1.4) suggested that the society solicit financial backing from the state. Powell

Figure 1.3. Illinois State Normal University was the original venue for the Illinois State Natural History Society and its museum. Photo from INHS archives.

Figure 1.4. Renowned explorer John Wesley Powell (center) was instrumental in developing what became the Illinois Natural History Survey. Photo from INHS archives.

addressed the Illinois General Assembly later that year and suggested an appropriation of $2,500 would cover the salary for a full-time curator as well as the costs for books and equipment.

The Illinois House and Senate approved the appropriation in February of 1867 and the governor immediately signed the bill into law. Powell was rewarded for his efforts by being named the Natural History Society Museum's first curator.

Powell left the museum in 1872 to head the U.S. Geological Survey in Washington, D.C. Upon Powell's departure, continued state support of the museum was made contingent on transfer of the museum from the society to the state. Thus, the Illinois Natural History Society ceased to exist when the transfer occurred. The museum, however, continued to reside at Illinois State Normal University with Stephen A. Forbes as the new curator (2).

Forbes served as curator until 1877 when the museum became the Illinois State Museum and moved to Springfield. Forbes (Fig. 1.5) and his staff at Normal metamorphosed into the State Laboratory of Natural History, which was given responsibility for collecting materials for the state museum and for carrying out plant and animal surveys throughout Illinois.

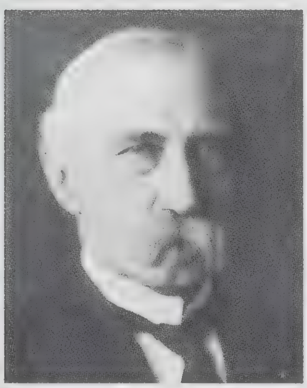

Figure 1.5. Stephen A. Forbes, first leader of the Illinois Natural History Survey, was a founding father of American ecology. Photo from INHS archives.

In 1882 Forbes accepted an additional post as State Entomologist. So, the office of the state entomologist and the head of the state natural history laboratory were filled by one person and located in one venue. When Forbes accepted an appointment to Illinois Industrial University (now University of Illinois) at Urbana in 1885, he also was allowed by the state to transfer his posts as state entomologist and natural history laboratory director. These offices took up residence in the Natural History Building at the intersection of Green and Mathew Streets at the UI campus.

The final metamorphosis of INHS took place in 1917 when the Office of the State Entomologist and Director of the State Laboratory of Natural History were combined into one organization, since known as the Illinois Natural History Survey. Stephen Forbes thus became the first of only eight "Chiefs" who have led the survey (3).

Today the survey remains an indispensable sensor of the ever-changing Illinois landscape. The fact that the organization, in one form or another, continues to exist after 150 years is testament to this. In the chapters that follow, we will not only detail, but analyze and synthesize 150 years of research on the many components that make up today's Illinois biological landscape.

WHAT EXACTLY IS "NATURAL HISTORY"

What sets the Earth apart from the other planets in our solar system, perhaps from all other planets in our galaxy, is simple; it is life—an amazing and bewildering variety of life that we call *biodiversity*. From the ocean depths to the highest mountain peaks, the Earth is enveloped in a mantle of living organisms. Organisms vary in size from bacteria to blue whales and have colonized virtually every available habitat on earth (Fig. 1.6). Even the extreme conditions surrounding the poles support their contingent of species. This variety of life has led to a flourishing of the natural sciences. With its origins dating back to Aristotle, natural history can be broadly defined as the systematic study of any category of natural objects or organisms and historically was generally more descriptive than experimental. To most scientists this definition has evolved over time into an umbrella term covering the numerous sub-disciplines of biology that pertain to the study of plants and animals in their natural environments.

We in Illinois are extremely fortunate and proud of our portion of worldwide biodiversity and subsequent opportunities for naturalists (those who study natural history). In the appendix to *Our Living Heritage: The Biological Resources of Illinois* (4), entomologist Susan Post undertook a year-long project to determine how many described species existed in Illinois. The list of species did not spring from a single source, but resulted from an exhaustive search of the literature and a query of biologists familiar with diverse groups of Illinois organisms. While her final tally was acknowledged to be lacking certain groups (protozoa, bacteria, and nematodes), it still was an impressive number, 53,754! Why so much diversity occurs in Illinois is a complex and interesting story. Chapter 2 describes how Illinois' geological history has shaped the landscape in which our plant and animal communities are found.

From a strictly human perspective, this biological diversity is the most important, yet least understood, of all natural resources. The diverse species provide most of the life-support materials upon which humans ultimately rely. Each species is unique, as E.O. Wilson so eloquently states, "a magic well of eons-old genetic information"

Figure 1.6. Life can exist in the most inhospitable places such as this tree from the genus *Welwitschia* in the Namibian desert. Photo by M. Jeffords.

(pers. comm. to M. Jeffords)—information that we cannot afford to be without. Every species that is lost reduces the options for nature—and for us—to respond to a continually changing environment. We must take into account not only ecosystem functions, such as watershed protections with intact, biotically rich floodplains and carbon sequestration in our forests, but the management of game and other exploitable species for both human recreation and foodstuffs. While the theme of change resonates through this document, specific chapters focus on the details of Illinois' past and present. Chapter 3 looks at some of the principal methods for assessing environmental change—computer-based Geographic Information Systems and a far-sighted monitoring effort known as the Critical Trends Assessment Program. Chapters 6, 8, and 9 review both non-game and exploitable game species and how their populations have varied with time. Chapter 11 looks in detail at the science behind fisheries research at the survey. Here we see some of the major themes in fisheries ecology and management and consider the ways the survey has influenced these research areas.

Of our 53,574+ species, we know of at least 500 that fall into the category of threatened or endangered within Illinois. While the extinction, or more locally the extirpation, of species is a natural process and a worldwide phenomenon, the current rate of extinction is progressing at an unnaturally high rate. Scientists have found that the normal species extinction rate on a geological time scale is one species every 1,000 years. By 1950, however, the rate had increased to one species every 10 years. Today, the rate is conservatively estimated at one species per day! In this context, perhaps the least useful statement that a human can make regarding an organism is "What good is it?" Ignorance of the potential use of a species to humans is a poor excuse for the finality of extinction. Add to this the issue of global climate change and we paint a somewhat grim picture of the future of the earth's organisms.

When popular culture speaks of biodiversity issues, it often tends to focus on the vertebrates (particularly large mammals), collectively termed the "charismatic megafauna."

In Illinois, though, we have always had a balanced approach to biodiversity research and Illinois' invertebrate species and communities have never been neglected. Chapter 7 summarizes the available information on long-term changes in the terrestrial insect fauna and provides recommendations for conservation and management of terrestrial insect communities. Chapter 10 looks in detail at aquatic assemblages of organisms in the Phyla Annelida, Mollusca, and Arthropoda. Illinois mussels, in particular, have a large percentage of species that fall into the threatened or endangered category and this chapter discusses the ability of the state's waters to support them into the future.

All of the detailed accounts in *Canaries in the Catbird Seat* are important to our understanding of biodiversity. For despite its importance, biodiversity remains an enigma for most citizens. During April, 1994, a nationwide phone survey of 1,209 randomly selected adults revealed that 73 % were totally unfamiliar with the concept of "loss of biodiversity."

ILLINOIS HABITAT DIVERSITY THEN AND NOW

In general, the greater the number of habitats there are within an area, the greater the potential is for species diversity and the maintenance of healthy populations of various species. Habitat types originally found in Illinois included forests, prairies, savannas, marshes, fens, lakes and ponds, streams, and caves. Although each of these habitats continues to exist, most are exceedingly small and often rare because of the extensive urban and agricultural development that has occurred in Illinois during the past 150 years. Harvard entomologist E.O. Wilson has noted, ". . . humanity spread across the worlds. . . godstruck, firm in the belief that virgin land went on forever . . . ." (pers. comm. to M. Jeffords). Inevitably, as land use changed, the number of species and the population sizes of most declined. The decline in biodiversity is not usually the direct result of human exploitation (although numerous examples of this exist), but because of the habitat destruction associated with development and expansion of human activities. Chapter 4 looks at the major vegetation types that have occurred in Illinois and how they have changed since the last ice age, and more specifically, how settlement by European-Americans has forever altered the Illinois landscape.

Forests—Even though Illinois has nearly 100 habitat types, these fit nicely into three broad categories: prairies, forests (Fig. 1.7), and wetlands. In 1820 approximately 13.8 million acres of Illinois were forested. Today nearly 4.3 million acres of trees can be found in Illinois (5). Most of the forest acreage of today is second- or third-growth timber or pine plantations; only 13,500 acres of relatively undisturbed forests remain. Why is this important? Illinois forests provide habitat for over half of Illinois' native plants. In addition, 47% of Illinois' threatened and endangered species are forest inhabitants, and 75% of wildlife habitat in the state is found in forests. Under the current climate change scenario, Illinois forests are likely to continue changing, and one of the many applications of biological field data is their inclusion in predictive models. Chapter 16 explores how such models are now being used to address questions facing society, such as how will forest vegetation respond to a warming climate? What tree species are likely to be most affected? These models have been developed to "see what the future may hold for Illinois trees."

Figure 1.7. An example of a floodplain forest in Illinois—one of several forest habitats in the state. Photo by M. Jeffords.

Prairies—Early Illinois settlers were concerned with survival and making a new life in the prairies and forests. They navigated and explored, logged, farmed, and constructed. Resources appeared inexhaustible. Many of the first Europeans to see the Illinois country had crossed a vast ocean, snaked their way through a nearly impenetrable mountain range, and forged a path through 1,000 miles of dense, primeval forest. They did it with indomitable spirit and by sheer force of will. Yet when they reached the edge of the eastern deciduous forest, today approximated by the Indiana-Illinois border, they stopped in wonder and marveled at the splendor and incredible magnitude. Here was a landscape so different and so unique—a grassland that stretched for a thousand miles—their language had no word for it. In time this landscape came to be known as "prairie," a word derived from the French word for meadow. At first early settlers avoided living on the prairie. But soon they realized the prairie made excellent cropland, especially after John Deer invented the moldboard plow that allowed virgin prairie soil to be relatively easily broken. The wild prairies became cropland at an astonishing rate—approximately 3.3% per year (Iverson et.al. 1989). Over 300,000 people settled on the prairie in the period from 1830–1840, and by 1860 nearly all the prairies had disappeared. Ironically, in early Illinois, human developments existed as tiny islands in a "sea of grass." Today, the plants and animals that made up the Illinois prairie now exist only as equally tiny sanctuaries in a vast "sea of development." Given the fate of Illinois' prairies, it seems appropriate to use this endangered ecosystem as a model for ecological restoration activities. Chapter 13 explores the development of restoration ecology, centering on early efforts to establish tallgrass prairies (Fig. 1.8) and the contrasting approaches taken in the past by practitioners and researchers. Chapter 14 continues the discussion, but broadens the focus to restoration conducted at the population, species, and community levels, using examples from prairie,savanna/open woodland, and forest communities.

Wetlands/Aquatic habitats—A poll of current Illinois residents would find that most do not consider their state to be particularly wet. The early settlers, however, would have had a very different impression. Illinois originally had an estimated 8 million acres of wetlands. Since Illinois became a state in 1818, more than 95% of these have been drained (the tile shop was one of the first businesses to open its doors in areas of new settlement); a concomitant loss in the natural biodiversity that wetlands contain was inevitable. Today, high-quality wetlands (Fig. 1.9) that reflect presettlement conditions are rare. Only about 6,000 acres remain. To help our understanding of wetlands and aquatic systems in general, several chapters focus on these often neglected, even maligned habitats. Chapter 5 defines types of wetlands and how they have changed in Illinois, while providing information on the ecological and taxonomic characteristics of wetland plants. Chapter 17 looks at the development and legal debates concerning federal legislation and regulations designed to protect wetland functions. And certainly appropriate to this volume, Chapter 18 returns to the topic of restoration ecology, but with a primary focus on restoration efforts in Illinois aquatic habitats. As examples, two large-scale restorations of bottomland lakes along the Illinois River in central Illinois are examined.

Finally, we would certainly be remiss if we ignored the number two problem facing biodiversity (after habitat destruction), and that is non-native and invasive species. One of the most rapid changes that has occurred in Illinois is in the size of its non-native flora and fauna. Chapter 12 focuses on exceptionally invasive species in Illinois' terrestrial, aquatic, and agricultural landscapes and habitats and discusses programs designed to manage these invaders.

In 1890, Dr. A.W. Herre (6) commented on the demise of the Illinois landscape. "What a pity that some of it could not have been preserved, so that those born later might enjoy its beauty also." Fortunately, his lament was heard as remnants of nearly all the habitats that originally occurred in our state can be found in nature preserves, state parks, conservation areas, and other protected sites that are refugia for much of the state's biological diversity. Through the continued efforts of the scientists of the Illinois Natural History Survey, we have a vast storehouse of knowledge concerning Illinois' natural resources. It is our sincere hope that this work will assist future citizens, managers, scientists, and politicians in wisely protecting and managing this vital part of the Illinois landscape.

Figure 1.8. Tallgrass prairies support a profusion of changing floral displays such as the Pale Purple Coneflowers (*Echinacea pallida*) seen in this image. Photo by M. Jeffords.

Figure 1.9. Illinois contains a variety of wetlands including this unique swamp along the Cache River. It is the northernmost cypress swamp in the nation. Photo by M. Jeffords.

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CHAPTER 2

An Overview of Illinois' Geological History and Landscape

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OBJECTIVES

Starting with the pre-glacial environment, this chapter introduces the environment and major habitats of Illinois. Since the flora and fauna of any region are ultimately a function of geology, we describe how Illinois' geological history has shaped the landscape in which Illinois' plant and animal communities are found. The history of the formation and deformation of bedrock, changing river systems over geological time, and, especially, multiple glacial episodes are discussed. Present day ecoregions of Illinois (Driftless Area, Southeastern Wisconsin Till Plains, Central Corn Belt Plains, Interior River Valleys and Hills, Interior Plateau, and Mississippi Alluvial Plain) are also presented using the classification system recently developed by the U.S. EPA, and this is compared with another classification system, Illinois' Natural Divisions. Finally, after briefly describing Illinois' climate, we provide an overview of Illinois' ecological communities.

INTRODUCTION

When the first European settlers arrived in what is now Illinois, they saw a wealth of natural diversity in the landscape. Studies of the natural resources of Illinois began soon after it gained statehood in 1818. Over the past 190 years the efforts of botanists, zoologists, geologists, and other scientists have resulted in a vast accumulated knowledge; probably more information is available about the natural resources of Illinois than just about any place else on earth (1). This knowledge is contained in both a voluminous published literature as well as in natural history collections.

At the time of European settlement, the land cover of Illinois was about 55% prairie and 42% forest (revised from 2, see Chapter 3). Over the past 160 years most of the landscape of Illinois has been converted to agriculture and urban areas. As a result, less than 1% of the original landscape is still extant, and Illinois now ranks near the bottom of the 50 states in this respect. Perhaps because so much of our natural heritage has been lost, Illinois has become a leader in the movement to inventory, protect, manage, and study what is left.

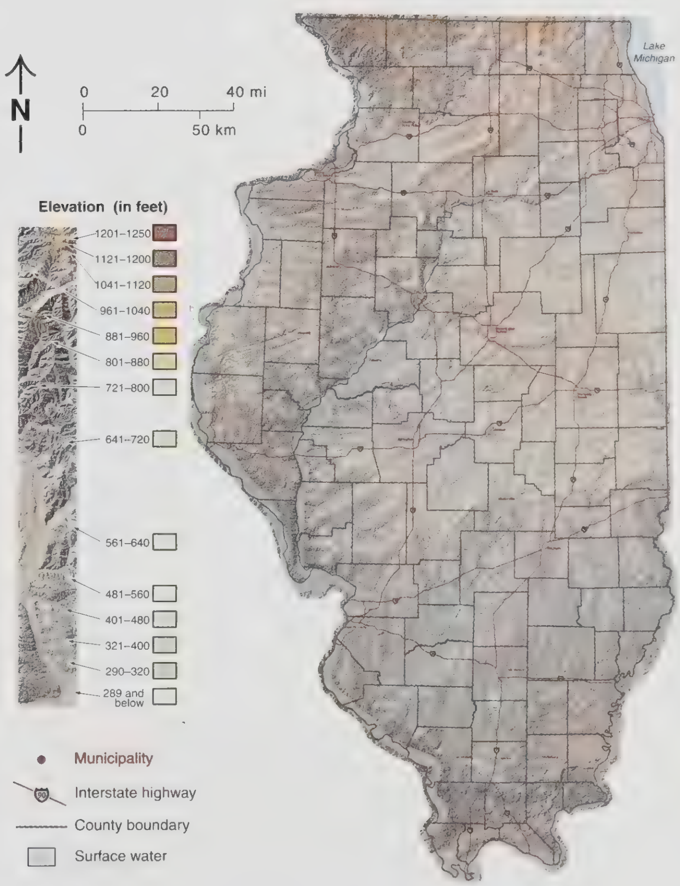

Figure 2.1. Surface topography of Illinois. After Luman et al. (62).

GEOLOGY SHAPING ILLINOIS' LANDSCAPE

The landscape and ecoregions of Illinois have been shaped by geological processes associated with the formation and deformation of its bedrock, the confluence of several mid-continent river systems, and continental-scale glaciation (Fig. 2.1). Landscapes form by the interplay of land construction and erosion. With time, drainage systems tend to become longer and more integrated. The lithification[1] of deposits of shallow seas during the Paleozoic Era (more than 290 million years ago) formed much of the bedrock in Illinois. Regional earth movements caused warping and faulting of

* Chapter authorized by the Director of the Illinois State Geological Survey.

1. **Lithification** is the process of rock formation by compacting and cementing sedimentary deposits.

a mixture of minerals that provided a nutrient base for plants. The glaciers rearranged some pre-glacial drainage ways and imposed new drainage ways on other parts of the landscape (Fig. 2.4). Dramatic changes in climate, creation of complex glacial landforms, widening and incision of river valleys by huge meltwater floods, and deposition of wind-blown silt over much of the state are effects of the last glacial episodes. These changes had a significant impact on the type and distribution of native plants and animals that the earliest settlers discovered on the landscape. During interglacial episodes, streams deepened and widened their valleys and developed more organized stream networks. Modification of the landscape continues today by both natural and human processes.

THE PRE-GLACIAL ENVIRONMENT

The landscape prior to the Pleistocene glaciations was much rougher than exists today at the land surface, except in the unglaciated areas—the northwest and southernmost regions of the state. The topography may have resembled the present day landscape of the Appalachians of eastern Kentucky. It featured broad, shallow valleys with sandy floodplains. The uplands were covered by a thin soil derived from weathering rock. River drainage patterns were partly controlled by bedrock geology (the type of rock or *lithology*) and structure (the pattern and shape of rocks as a result of folding, warping, and faulting). Drainage systems tended to route around, or to be diverted by, bedrock that is relatively resistant to erosion.The ancient Mississippi River (Fig. 2.3) originally flowed in a now-buried valley from the northwest corner of Illinois near Galena to

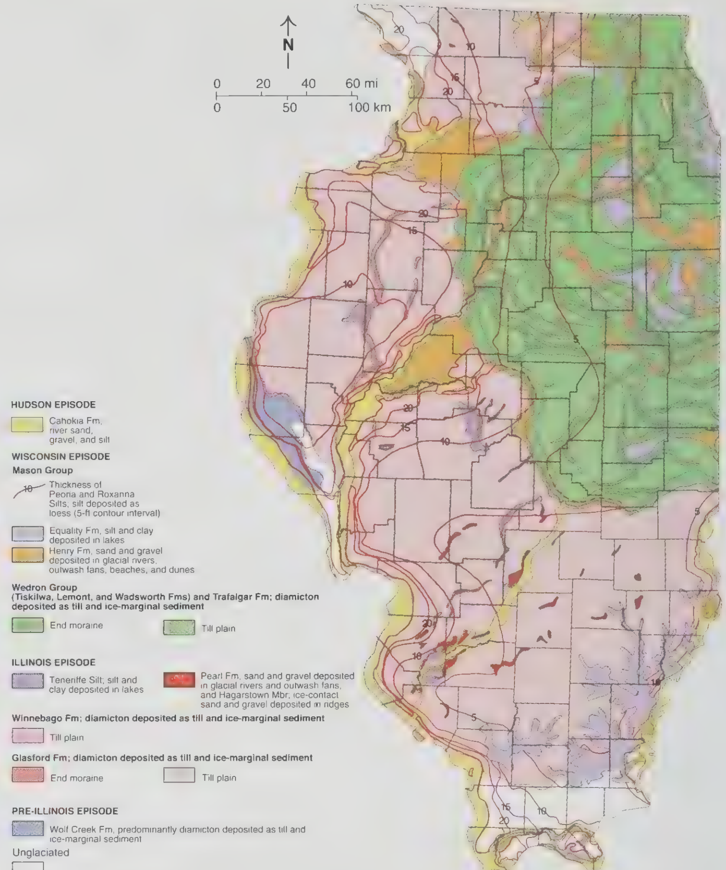

Figure 2.3. Surficial geologic units of Illinois. Diamicton is an unassorted mixture of clay, silt, sand, and gravel. The thickness of loess that blankets Wisconsin Episode and older units is represented by red contours. Source: (23); digitally adapted by B.J. Stiff.

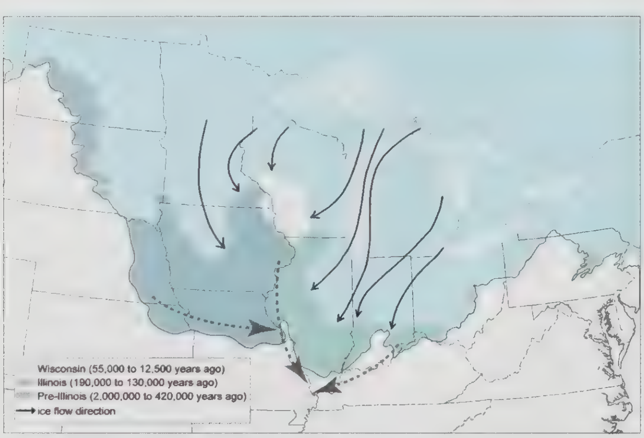

Figure 2.2. Furthest extent of Pleistocene ice advances across the Midwest. Open arrows indicate general ice flow directions; closed arrows indicate major meltwater drainageways. Source: (16).

Tazewell and Mason counties, where it was joined by the westward-flowing ancient Mahomet River. From there, the ancient Mississippi flowed southward down the path of the present-day Illinois River. The broadness of the valley just south of the confluence (Fig. 2.4A) attests to erosion by actively migrating streams and possibly high meltwater discharges in the early Pleistocene. The ancient Iowa River occupied portions of the modern Mississippi Valley upstream of Grafton and joined the ancient Mississippi

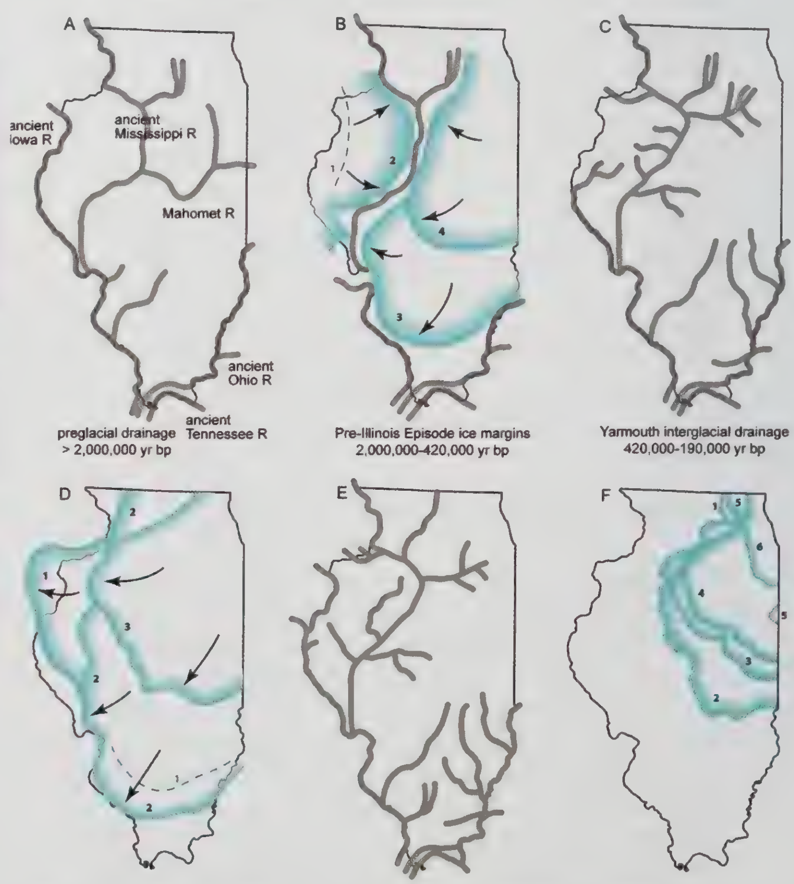

Figure 2.4. Patterns of glacial ice lobe advance and interglacial drainage. Source: (16).

where the modern Mississippi and Illinois rivers join (Figs. 2.2, 2.4A; 5).

The bedrock surface predominantly comprises sediments deposited in shallow seas and nearshore environments between about 500 and 300 million years ago, during the Paleozoic Era. The regions of Illinois where bedrock is near or at the surface have distinct landscapes controlled in part by the lithology and structures. Further, the lithologies can have an intimate connection with the biologic communities that exist.

Shale and weakly-cemented sandstones are easily eroded. Regions underlain by these rocks tend to be low lying plains with low relief and thick soil cover (6). By contrast, strongly-cemented sandstones are highly resistant to erosion. The rugged cliffs of the Shawnee Hills in the south occur because resistant sandstones contrast with adjacent erodable shales. Sandstones tend to have low mineral content, so they support unique biological communities on thin soil cover.

Karst is a three-dimensional landscape that was formed by the dissolution of soluble bedrock, such as limestone or dolomite. In Illinois, the typical karst landscape is expressed as gently rolling plains with numerous depressions. This topography is caused by the occurrence of relatively pure limestones, carbonate rocks made from the shells of marine organisms, that have low resistance to erosion and weathering. Fissures, crevices, and caves are dissolved out of the rock by groundwater. When openings in the top of subterranean conduits form through collapse or solutional activity, sinkholes form as the overlying sediments are drawn underground. Caves, springs, and seeps are common in Illinois' karst landscapes. About 10% of Illinois is classified as karst, and the region surrounding Illinois Caverns State Natural Area in the southwest is typical of this landscape (7).

Dolomite is also a carbonate rock, but the addition of the chemical magnesium makes it harder and more resistant to erosion. Dolomitic areas tend to feature high plains or low hills (6). Dolomite underlies the Driftless Area in northwestern Illinois, contributing to its rough topography.

Bedrock lithologies, structures, and pre-glacial drainage patterns all influenced the ensuing glacial events that shaped most of the present land surface. The routes of the great mid-continent river systems— the Mississippi, Illinois, Wabash, and Ohio and their ancestors— were rerouted by positions of former ice margins, covered by thick glacial deposits, accentuated by glacial landforms, or shaped by meltwater draining glaciers and glacial lakes not only in Illinois, but in adjacent Great Lakes states as well.

THE PRE-ILLINOIS EPISODE

The evidence of the earliest glacial and interglacial episodes in Illinois is sparse. However, one or more glaciations are known to have affected the state in the mid- to late Pleistocene Era between about 2 million and 420 thousand years ago and prior to the Illinois Episode[2]. The early history of these glaciations is poorly known in Illinois because the deposits were either deeply buried or extensively eroded during subsequent glacial episodes, and because dating materials from that time period is difficult. At the onset of glaciation but before ice reached Illinois, abundant meltwater flowed from the glacial margins and deeply incised several existing bedrock valleys. Ice flowing from the northwest overrode the ancient Iowa River (Fig. 2.4B). Ice flowing out of the northeast may have reached as far south as the Shawnee Hills (described below), though the evidence is limited. This ice lobe overrode the Mahomet Valley, filling it with a cover of stream, lake, and glacial deposits. As a consequence, the Mahomet Valley drainage was diverted southward to near the modern Ohio River valley (Fig. 2.4B). The ancient Mississippi was constrained between the two ice lobes flowing from the northwest and northeast, respectively (Fig. 2.4), and its valley also received a thick sequence of sand and gravel. After ice retreat and during the warm Yarmouth Interglacial Episode, about 420 to 190 thousand years ago (8, 9), when the climate was temperate to subtropical and much the same as the present, the ancient Mississippi reoccupied its former course from Galena to Grafton, but the partially filled-in Mahomet Valley no longer served as a major drainageway (Fig. 2.4C; 5).

THE ILLINOIS EPISODE

During the Illinois (glacial) Episode, which dated from about 190 to 130 thousand years ago (9, 10) three major ice advances extended across the state from the northeast (Figs. 2.2, 2.4D). Each advance diverted the flow of the ancient Mississippi westward. At least one ice advance crossed the modern Mississippi (11, 12) and reached south to the flanks of the Shawnee Hills. Parts of the lower reaches of the modern Illinois and Kaskaskia rivers functioned as main outwash conduits during the Illinois glaciations. Most of the Illinois Episode sediments in northeastern Illinois were eroded by later ice advances, but relatively thin, sandy glacial deposits (till) and sand and gravel (outwash) deposits were preserved in some bedrock valleys (13, and many others). In addition, during the last part of the Illinois Episode, strong westerly winds eroded sand and silt from outwash plains and deposited the sediment on uplands as dunes and blankets of loess (windblown silt).

The ensuing Sangamon Interglacial Episode, about 130 to 55 thousand years ago, was an interval of moderate climate not unlike today (14). The ancient Mississippi River resumed its ancestral course and entered a bedrock valley just east of Peoria (Fig. 2.4E; 15, 16). The ancient Iowa River also resumed its old course, but the Mahomet Valley had been completely buried by glacial sediment by this time.

The landscape of more than half of the state is covered with Illinois Episode glacial deposits underneath a blanket of younger loess (Fig. 2.3). These deposits mark the southernmost extent of glaciation in the Northern Hemisphere (3). The topography is etched by the creeks and rivers that are tributaries to the Mississippi, Illinois, Kaskaskia, and Wabash rivers (Fig. 2.1). Drainages tend to

2. Well-recognized glacial sedimentary units and interglacial buried soil units are given the formal name of an Episode. Episodes are time-transgressive, that is, they occur at varying times in varying places as ice sheets advance and retreat. No glacial or interglacial episodes are formally recognized prior to the Illinois Episode.

have more dendritic patterns than the glaciated landscape of Northeast Illinois because the landscape has been subjected to wind and water erosion for a much longer time—about 130,000 years. Few glacial landforms are found in this portion of the state. Perhaps the most distinct landforms that punctuate the southern Illinois Episode landscape are northeast-to-southwest trending ridges composed of sand, gravel, and till-like sediment (16, 17, 18, 19, 20; elongate red features, Fig. 2.3). Nearer the edge of the Illinois Episode glacial limit, the glacial deposits are thin and surface landforms tend to reflect (preglacial) bedrock features rather than distinct glacial features.

THE WISCONSIN EPISODE

Glaciers remained north of Illinois during much of the last glacial interval, the Wisconsin Episode, which occurred between about 55 thousand and 15 thousand years ago (21, 22). Little is known about the early to middle parts of the Wisconsin Episode because deposits from that interval were subsequently eroded or deeply buried (3, 23).

Unlike earlier ice advances, the last glaciers advanced only into northeastern Illinois (Fig. 2.2). The Lake Michigan and Huron-Erie lobes flowed out of the depressions now occupied by Lakes Michigan, Huron, and Erie, respectively. The Lake Michigan lobe first entered Illinois about 29,000 years ago. At its furthest advance, the glacier covered only the northeastern two-fifths of the state (Fig. 2.3), but the effect upon the landscape of the whole state was profound. Beneath the glacier, some pre-existing Pleistocene deposits were completely eroded away to expose the bedrock (24). The present-day configurations of the Mississippi and Illinois rivers were formed during the Wisconsin Episode (about 20,000 years ago; 25) when the ice lobe reached its westernmost extent near Peoria and blocked the water flowing through the ancient Mississippi River. The water spilled over a drainage divide near Rock Island, joining the ancient Iowa and Mississippi rivers to form the modern Mississippi channel. Climate warming starting about 19,500 years ago and caused the end of the Lake Michigan lobe. Since that time, the glacial margin retreated back from its terminal moraine towards the Lake Michigan basin with repeated small advances. This created the overlapping end moraine systems that distinguish the landscape of northeastern Illinois (Figs. 2.3, 2.4F). During the middle to late Wisconsin Episode, the Illinois Valley became the main drainageway (Fig. 2.4), carrying meltwater and abundant sediment away from the retreating glacier margin. Lakes formed repeatedly between the ice front and existing moraines whenever major streams were blocked. The landscape between northeastern Illinois moraines often reflects these flat glacial lake beds.

The Mississippi and Ohio rivers continued to serve as the main regional conduits for meltwater discharge during deglaciation of the Midwest until the Great Lakes ice-lobe margins retreated into the lake basins and new outlets to the Atlantic Ocean opened. In response to sea-level change, overall climate change, and changes in sediment transport and deposition due to melting ice caps, the large mid-continent stream systems experienced large cycles of downcutting and refilling with sediment. By the start of the Wisconsin Episode, the Mississippi and Ohio rivers had down cut below their modern flood plains. By about 18,000 years ago, by contrast, meltwater from the Wisconsin Episode glaciers filled the valleys with outwash to levels above the modern floodplains (21, 26). The aggrading sediment slowed the flow of water through tributary rivers and created slackwater lakes that extended far upstream. Today, remnants of these slackwater lakes are expressed as terraces and broad low flat areas in the tributary valleys (18; Fig. 2.3). They are cored with clay, silt, and fine sand and occupy intermediate positions in the landscape, between the modern river bottoms and the uplands.

With further retreat of the glacier margin caused by the warming climate and a brief minor readvance during a cooling period, ancestral Lake Michigan was impounded between the retreating glacier margin and the moraines bordering present-day Lake Michigan (Fig. 2.3). The glacial lake existed at several levels between about 13,500 to about 11,000 years ago. Its level rose up to 60 feet above present (27) in response to glacial melting, variation in the amounts of precipitation, and reorganization of drainage through the Lake Huron and Lake Erie depressions toward the Atlantic Ocean (28). The lake dropped to an extreme low, at least 200 feet below present, when the ice margin retreated north of the Straits of Mackinaw about 10,000 years ago. The lake level began to rise again about 6,300 years ago, reaching a post-glacial high about 25 feet above present, some 5,500 years ago, and then gradually lowered to its modern level (27). The landscape surrounding the southern Lake Michigan rim includes the remnants of the lake plains, lagoons, beach ridges, spits, and dunes associated with lake-level fluctuation (Fig. 2.3).

Throughout the Wisconsin Glacial Episode and early Hudson Post-glacial Episode, the lowermost reaches of the Illinois Valley also responded to events downstream in the Mississippi Valley. Repeated episodes of flooding, aggradation, and incision in the Mississippi Valley are attributed to discharges from Glacial Lake Agassiz, a vast impoundment containing all of the drainage from east of the Rockies that now enters Hudson Bay, Canada (Fig. 2.5; 29, 30). This caused episodic ponding in the lower Illinois Valley and the accumulation of lake silt and sand in the valley and its tributaries (31,32). The deposits were left as terraces along the valley walls upon re-incision of the river system.

Landscapes of the Wisconsin and Illinois episodes contrast markedly, in part due to the nature of the glacial episodes that constructed them, and in part due to the duration of post-glacial modification (Fig. 2.1). The Illinois glaciation landscape consists primarily of broad gently rolling to flat till plain with limited belts of elongate ridges cored with sand and gravel and mixed glacial sediment. The surface water drainage is well-organized, with stream valleys of relatively high relief and a dendritic tributary network. By contrast, the Wisconsin glaciation landscape is smoother and is accentuated by long arcuate, sub-parallel ridges (end moraines) cored with glacial till that mark the former positions of ice margins. There are many of these

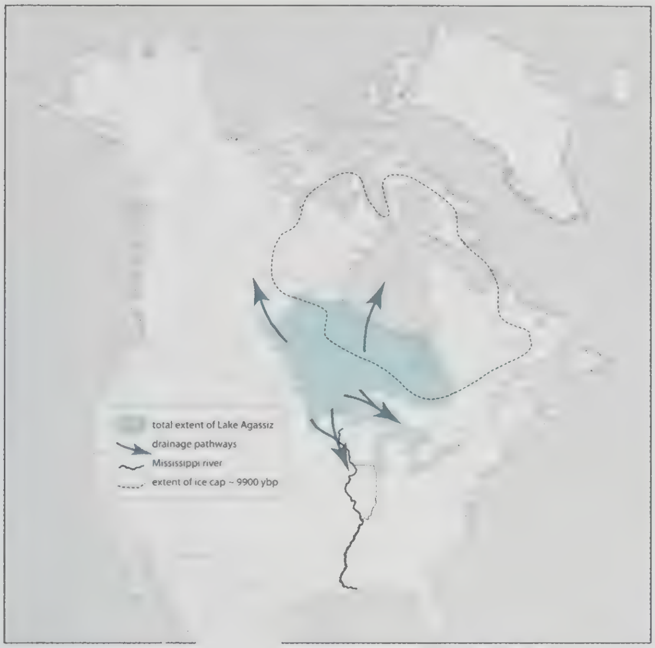

Figure 2.5. Generalized maximum extent of Glacial Lake Agassiz, its major drainageways, and relation to the Laurentide ice cap. After Teller and Leverington (63).

and some exhibit high relief hummocky topography (Figs. 2.1, 2.3). Their pattern on the landscape documents the path of the retreat of the Lake Michigan lobe margin. Areas between the moraines are generally flat and include a few large areas of lake plain (Fig. 2.3). The moraines constrain the major stream valleys. As well, the valleys are smaller and have lower relief than on the Illinois Episode landscape. In the northeastmost part of the state, ice-block depressions (kettles), high relief hummocky topography, and ice-contact sand and gravel deposits create a unique terrain, different from that of the rest of the Wisconsin Episode landscape and the rest of the glaciated part of the state. This landscape indicates that large parts of the glacier became stagnant—disconnected from the main flowing part of the glacier—and melted in place. The surface water drainage in this terrain is disorganized and includes abundant enclosed depressions that are occupied by wetlands and lakes.

THE HUDSON EPISODE

The events of the continental glaciations in Illinois over the past 1.5 million years created our present landscape and left up to several hundred feet of sediment over the bedrock surface. Now, in the current Hudson Episode, about 10,000 years ago to the present, this landscape continues to be modified by the actions of wind, water, people, and other organisms. Indeed, many of the same processes occur today as in the glacial times, although modern rates of erosion and deposition tend to be more subdued than during glacial periods.

Loess deposited by windstorms during the waning phases of glaciation covers much of the state. The loess is 10–20 feet thick on the uplands next to the source areas in the valley bottoms of the Mississippi, Illinois, and Wabash rivers, but thins away from valleys to a blanket a few feet thick (Fig. 2.3; 33). This windblown silt provides the parent material for the fertile soils that supported the vast prairies and now support the agricultural industry of Illinois. However, the loess is highly erodible, and thus is readily transported back into our waterways. Some soil is eroded from gulleys and rills that develop in fields. However, because of the low slopes on uplands and the floodplains of the major rivers, that eroded soil is likely not transported far in any given erosion event. Most of the sediment transported by streams entered the water through failures of steep valley walls and erosion of channel banks as streams migrate laterally or widen their channels (34, 35).

Alluvial fans and fan deltas are constructed of gravel, sand, and silt deposited at the mouths of tributaries where the stream gradient abruptly lessens. Prominent fan deltas that can be found at the mouths of many of the streams that enter the lower Illinois and Mississippi rivers have been developing throughout the Hudson Episode. The fan deltas of tributary streams also provide significant areas of sediment storage and are potential sediment sources when river energy level is greater during floods.

The landscape that the first European settlers encountered is very different from today's due to a combination of climate and land use changes (36, 37, 38). A major influence on the modern landscape has been the construction of drainage networks during the transformation of prairies to agriculture (e.g., 39). Natural swales and channels have been deepened and straightened since the late 1800s. Extensive tile networks have been tied into the stream networks. As a result, most wetlands have been drained, and water landing on the ground surface as precipitation runs off to stream channels much more quickly.

ILLINOIS ECOREGIONS

Landscapes are often described by differences in topography, glacial history, bedrock geology and structure, soils, and the distribution of native plants and animals. In Illinois, several systems for classifying biological landscapes have been proposed (40, 41, 42, 43, 44), and perhaps the best known of these to biologists is the natural divisions of Illinois (45). The natural divisions of Illinois were put forth in 1973 in a technical report authored by then state botanist John Schwegman and colleagues, who used natural features to divide Illinois into 14 natural divisions (Fig. 2.6). According to Schwegman et al. (45), "Natural divisions are geographic regions of a larger entity like a state or a continent. A division contains similar landscapes, climates and substrate features like bedrock and soils that support similar vegetation and wildlife over the division's area. Natural divisions help conservationists classify land for purposes like protecting natural diversity." Today, this classification system still serves as a framework for identifying significant natural features that should be included in Illinois' nature preserve system and to help set priorities for land acquisitions.

In this chapter, we use a recently developed (46) system of ecoregion classification implemented throughout North America (47). A major advantage of using this classification system is that it is nationally implemented

and encourages consistent land management by facilitating communications and partnerships across political units within ecoregions which occur in more than one state. Under this system, Illinois contains six Level III ecoregions (Fig. 2.7), which are delineated on the basis of geology, soils, glacial history, and plant and animal communities, as well as human ecological influences. These Level III ecoregions (Table 2.1) are nested within Level II and then Level I ecoregions which are broad-scale categories suitable for international, national, and regional levels of analysis. In addition, elements of other Illinois landscape classification schemes are evident in the system developed by the U.S. Environmental Protection Agency, including portions of The Nature Conservancy ecoregions and the North American Bird Conservation Initiative's Bird Conservation Regions (see Figs. 1 and 2, respectively, in 48).

The ecoregion descriptions given below follow USEPA (47) and Woods et al. (49). Because many naturalists in Illinois are more familiar with Illinois' natural divisions (45), we have attempted to correlate the two classification systems.

DRIFTLESS AREA

The Driftless Area (Fig. 2.7) is found in extreme northwestern Illinois, and extends into neighboring Iowa and Wisconsin. It comprises a little more than 1% of the land area of Illinois and corresponds roughly to the Driftless Area of Schwegman et al. (45).

The Driftless Area lacks evidence of glaciation. The landscape does not include glacial landforms or sediments transported by glaciers from far distant locales as are present in much of the Midwest. From this evidence we know it escaped the Pleistocene glaciers. Lacking glacially

Figure 2.6. Current natural divisions of Illinois, based on Leighton et al. (42) and Schwegman et al. (45). The Natural Divisions classification scheme delimits 15 divisions in Illinois, with most of the divisions subdivided into sections, resulting in a total of 34 units. Factors taken into consideration included topography, soils, bedrock, glacial history, and the distributions of plants and animals. The original publication of Schwegman et al. (45) included a map as well as text describing the main features of each of the divisions and sections. Seven major categories of terrestrial plant communities were used in that publication: forest, prairie, fen, marsh, sedge meadow, and bog.

Figure 2.7. Ecoregions of Illinois after USEPA (47) and Woods et al. (49). Level III ecoregions are shown with colors, select units of many of the Level IV ecoregions are indicated with letters, as follows: a. Paleozoic Plateau/Coulee Section; b. Savanna Section; c. Rock River Drift Plain; d. Kettle Moraines; e. Rock River Hills; f. Sand Area; g. Illinois/Indiana Prairies; h. Valparaiso-Wheaton Morainal Complex; i. Chicago Lake Plain; j. Western Dissected Illinoian Till Plain; k. Upper Mississippi Alluvial Plain; l. River Hills; m. Southern Illinoian Till Palin; n. Glaciated Wabash Lowlands; o. Wabash River Bluffs and Low Hills; p. Wabash-Ohio Bottomlands; q. Karstic Northern Ozarkian River Bluffs; r. Southern Ozarkian River Bluffs; s. Cretaceous Hills; t. Northern Shawnee Hills; u. Southern Shawnee Hills.

Table 2.1. Ecoregions of Illinois following USEPA (47), as modified by Woods et al. (49). Illinois falls completely within the Level I ecoregion "Eastern Temperate Forests."

Level II	Level III	% Area	Level IV	% Area
Mixed Wood Plains	Driftless Area	1.16	Savanna Section	0.51
			Paleozoic Plateau/Coulee Section	0.65
Central USA Plains	Southeastern Wisconsin Till Plains	2.31	Rock River Drift Plain	1.09
			Kettle Moraines	1.22
	Central Corn Belt Plains	45.92	Illinois/Indiana Prairies	34.99
			Rock River Hills	3.36
			Sand Area	3.53
			Chiwaukee Prairie Region	0.09
			Valparaiso-Wheaton Morainal Complex	3.14
			Chicago Lake Plain	0.78
			Kankakee Marsh	0.02
Southeasterm USA Plains	Interior River Valleys and Hills	48.00	Western Dissected Illinoian Till Plain	11.74
			River Hills	5.04
			Southern Illinoian TIll Plain	20.71
			Upper Mississippi Alluvial Plain	3.38
			Middle Mississippi Alluvial Plain	1.17
			Karstic Northern Ozarkian River Bluffs	0.65
			Southern Ozarkian River Bluffs	0.38
			Wabash-Ohio Bottomlands	2.71
			Cretaceous Hills	0.42
			Glaciated Wabash Lowlands	0.47
			Wabash River Bluffs and Low Hills	1.34
	Interior Plateau	2.43	Northern Shawnee Hills	1.05
			Southern Shawnee Hills	1.37
	Mississippi Alluvial Plain	0.19	Northern Holocene Meander Belts	0.19

deposited debris, this Level III ecoregion is characterized by rugged terrain—loess-capped bluffs, dolomite-capped mounds, and high rocky palisades (Fig. 2.8). The area has not only the state's coldest winters but also the highest point—Charles Mound (1,235 feet). The soils of the Driftless Area are composed of wind-blown loess, disintegrated bedrock, and flood deposits. At one time most of the landscape was clothed with hardwood forest. Oak and maple forests, and coldwater, spring-fed streams are major features of the landscape. The Driftless Area is divided into two Level IV ecoregions, the **Paleozoic Plateau/Coulee Section** to the southwest (Fig. 2.7a) includes deep rugged valleys, algific slopes[3], caves, springs, and steep-sloped hills, whereas the **Savanna Section** (Fig. 2.7b) is typified by vestiges of a broad plateau.

3. An **algific slope** is a type of talus slope at the bottom of a limestone cliff which provides a cold microclimate as a result of the unusual configuration of the talus in relation to cavernous bedrock, which traps cool air in the winter in upland sinkholes, releasing it into the talus below in the warmer months.

Although the glaciers advanced around this area, debris from their meltwaters blocked the southeast outlet of Apple River, causing it to cut a new channel. As the river cut

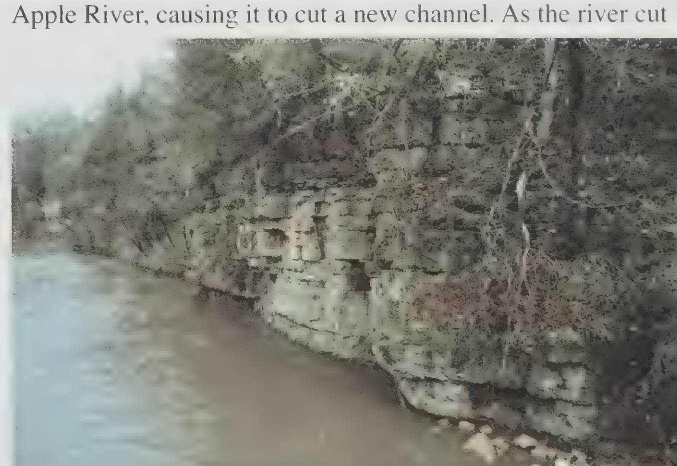

Figure 2.8. Rocky, limestone bluffs such as this are commonly found along stream margins in the Driftless Area of Illinois. Photo by M. Jeffords.

through the masses of limestone, dolomite, and shale to form its new channel, it also formed a rugged and picturesque canyon. This iceless region provided a haven that allowed certain plants and animals to survive the glacial periods. The Iowa Pleistocene Snail (*Discus macclintocki* Baker) and the Bird's-eye Primrose (*Primula mistassinica*) are among these relicts.

SOUTHEASTERN WISCONSIN TILL PLAINS

The Southeastern Wisconsin Till Plains (Fig. 2.7) occur in the northern border counties of Illinois from Stephenson County to nearly the Lake Michigan shoreline. Comprising slightly more than 2% of Illinois land area, this region encompasses northern portions of the Rock River Hill County and Northeatern Morainal natural divisions of Schwegman et al. (45). The Southeastern Wisconsin Till Plains are characterized by increasing frequency of kettle lakes to the east (the **Kettle Moraines** Level IV ecoregion, Fig. 2.7d). The only true bogs in the state and most of Illinois' natural lakes are found here. Kettle lakes in this area formed when blocks of glacial ice buried in sediment melted, leaving behind now water-filled depressions. To the west in the **Rock River Drift Plain** Level IV ecoregion (Fig. 2.7c), oak savanna and prairie once occupied the larger expanses of upland while forests were equally abundant along watercourses. White Pine (*Pinus strobus*), Canada Yew (*Taxus canadensis*) and Yellow Birch (*Betula allegheniensis*)—northern forest relics—can still be found in this division. Prairie knobs (islands of prairie that were either too hilly or troublesome to farm) support plant communities which include Pasque Flower (*Pulsatilla patens*) and profusions of Pale Purple Coneflower (*Echinacea pallida*). Presently, dairy farms and agricultural fields of livestock forage and grains replace the majority of the natural communities (49).

CENTRAL CORN BELT PLAINS

The Central Corn Belt Plains (Fig. 2.7) is the second largest Level III ecoregion in the state, encompassing nearly 46% of the land area in Illinois, and containing seven level IV ecoregions. It extends from somewhat north of U.S. Highway 20 in the northern part of the state south to somewhat north of Interstate 70 in the southcentral part of the state. This Level III ecoregion is largely equivalent to the Grand Prairie natural division of Schwegman et al. (45) with portions of their Rock River Hill Country, Northeastern Morainal, and Mississippi River Section (especially Illinois River and Mississippi River Sand Areas) natural divisions included.

The Central Corn Belt Plains comprise a vast plain punctuated by morainal ridges with gently to moderately rolling topography, much of which was formerly occupied by tallgrass prairie. The grassland landscape was so different and expansive that the early travelers had to turn to the sea for analogies, calling the area "a sea of grass" or "a vast ocean of meadow-land." In time this landscape came to be known as "prairie." The fertile soils are young and high in organic content. They were developed from deposited loess, lakebed sediments, and glacial drift. Natural drainage was poor, resulting in many marshes and prairie potholes. The prairies were a veritable wildflower garden, containing several hundred species of grasses and forbs.

Forests interrupted the landscape on floodplains, on slopes bordering streams, along river bends, and in isolated prairie groves.

The Level IV ecoregion **Chicago Lake Plain** (Fig. 2.7i) represents the area covered by ancestral Lake Michigan, which is now occupied by the city of Chicago. It includes sand-cored, curved beach ridges and spits with intervening low lake plains and former lagoons associated with the past glacial and post-glacial phases of the lake.

Encircling the Chicago Lake Plain is the **Valparaiso-Wheaton Morainal Complex** (Fig. 2.7h), a belt of glacial landforms that includes stratified deposits formerly in contact with glacial ice, such as deltas, outwash fans, kames (conical hills of glacial debris), moraines (long ridges of glacial debris) and eskers (a ridge of sand and gravel from an ancient embedded glacial stream). This area has the most varied suite of glacial landforms, and exhibits some of the most rugged glacial topography, in the state of Illinois. Along the shores of Lake Michigan, sand dunes of varying sizes form natural dune and swale associations. Soils are derived from lakebed sediments, peat, beach deposits, and glacial drift and range in texture from sand and gravel to silty-clay loams.

One of the most interesting habitats in the Central Corn Belt Plains can be found in the **Sand Areas** Level IV ecoregion (Fig. 2.7f). Here, sand prairies (Fig. 2.9), sand savannas, and sand forests are the major habitats. Sand forests occur in areas of sand deposits where natural firebreaks have reduced burning frequency. These forest communities are distinguished by soil-moisture characteristics. Sand prairies occur on course-textured soils. They form on outwash plains and lake plains and range in soil moisture characteristics.

INTERIOR RIVER VALLEYS AND HILLS

The Interior River Valleys and Hills (Fig. 2.7) is the largest Level III ecoregion in the state, encompassing 48% of the land area, and containing 11 different Level IV ecoregions. This ecoregion includes most of the remaining southern and western portions of the state, excluding the Shawnee Hills. It occupies most of the major valleys of the Mississippi, Ohio, Illinois, and Kankakee rivers in the southern and western portions of Illinois. This ecoregion corresponds roughly to the following natural divisions of Schwegman et al. (45): much of the Upper Mississippi River and Illinois River Bottomlands Division, most of the Coastal Plain Division (except the southernmost tip at the junction of the Ohio and Mississippi rivers), all of the Middle Mississippi River Border Division, and virtually all of the Southern Till Plain and Wabash River Boarder, Ozark and Western Forest Prairie divisions. While these divisions from Schewgman et al. (45) appear to be lost at this level, most are represented in the ecoregion classification system as Level IV ecoregions.

A great variety of habitats occur in the Interior River Valleys and Hills, including bottomlands characterized by broad floodplains and gravel terraces formed by glacial floodwaters. Big rivers, including the Illinois, Ohio, and Mississippi, have oxbow lakes, and backwater lakes are found most commonly in the Illinois River and its major

Figure 2.9. An Illinois sand prairie. Photo by W. Handel.

tributaries south of LaSalle. Hallock (50) in the *The Sportsman's and General Guide* described this area: "The most noted sporting grounds in Central Illinois, if not in the whole State, lie upon the Illinois River. . .The game here is of great variety and abundance . . ." Much of this land was originally forested and forests still occur along the broad floodplains. Prairies, marshes, and mesic savannas also occurred.

The **Western Dissected Illinoian Till Plain** Level IV ecoregion (Fig. 2.7j) contains level to rolling uplands, interspersed with deeply cut rivers and ravines with well-developed floodplains (Fig. 2.10). It is a land of deep, forested ravines with intervening flat prairie openings. The area was covered by Illinoian-age glaciers, but bedrock outcroppings of sandstone, shale, and limestone are common in some locations. Two major units of the Western Dissected Illinoian Till Plain are separated by the Illinois River valley. Northwest of the Illinois River valley, the amount of prairie here once almost equaled the amount of forest. One interesting habitat type is the dry-mesic barren, also known as an oak opening. These barrens are transition zones between prairie and forest (see Chapter 4). In the southeastern unit of the Western Dissected Illinois Till Plain, the original vegetation was forest, with only 12% of the area in prairie. The presettlement prairies existed in large parcels on the uplands, and unlike the forests in this division, early settlers gave these prairies names. Both String Prairie and Brown's Prairie were found in this section. Very little prairie or forest remains today.

The Interior River Valleys and Hills Level III ecoregion also encompasses the narrow band of river bluffs and rugged terrain along the Mississippi River floodplain from Rock Island County to St. Clair County and the lower Illinois River valleys, represented in this classification system as the **River Hills** Level IV ecoregion (Fig. 2.7l). Bedrock cliffs and outcrops of limestone and sandstone are common along the river bluffs. Hill prairies occur atop south- and west-facing bluffs, while oak-hickory forests predominate in the ravines and cooler north-and east-facing slopes.

Deep deposits of loess (windblown silt) form high bluffs. Forests along the major river valleys trapped these dust-sized particles and the material accumulated to form high bluffs. Two peaks in Pere Marquette State Park at the mouth of the Illinois River are examples of loess deposits—McAdams Peak and Lovers Leap.

The topography of the River Hills is a result of the Pleistocene glaciers—the Illinoian and earlier episodes. Limestone underlies most of this section and forms cliffs along the river. Unusual habitats found here include limestone glades, loess hill prairies, and glacial-drift hill prairies.

Figure 2.10. Numerous habitat types can be found in the Western Dissected Illinois Till Plain, including forested ravines. Photo by M. Jeffords.

The largest Level IV ecoregion of the Interior River Valleys and Hills is the **Southern Illinoian Till Plain** (Fig. 2.7m). This ecoregion encompasses the area south of the Shelbyville Moraine, the Sangamon River, and Macoupin Creek. The Illinoian Episode glacial margin reached its southernmost limit just beyond the southern limit of this Level IV ecoregion. The bedrock consists of sandstone, limestone, coal, and shale. A layer of thin soil with poor internal drainage, usually loess or till, covers the bedrock. Many of the soils have a high clay content leading to "claypan" subsoil. From north to south the glacial till becomes thinner.

This division varies from a relatively flat plain drained by the Kaskaskia River and containing mostly prairie to a rolling, hilly topography which once was mostly forested. Throughout this ecoregion, post oak flatwoods occur on the hard, clay-rich soil that impedes deep root development. Trees do not live excessively long in a flatwood forest. They undergo a regular cycle of 150 to 200 years, and when they reach a certain size, the trees inevitably blow down because of their shallow root penetration in the clay soil.

The last major units of the Interior River Valleys and Hills are the Level IV ecoregions found to the east, along the Wabash River drainage. Here, three Level IV ecoregions, the **Glaciated Wabash Lowlands**, the **Wabash River Bluffs and Low Hills**, and the **Wabash-Ohio Bottomlands** (Figs. 2.7n, o, and p, respectively) reflect differing communities corresponding roughly to the Wabash River Border Division of Schwegman et al. (45).

In presettlement days, the eastern border of Illinois contained the great trees that made up the last stronghold of the eastern deciduous forest. Traces of this magnificent forest

still remain in the landscape surrounding the loess-covered hills and bottomlands of the Wabash River and the valleys and forests of the Vermilion River. The area is underlain with limestone, sandstone, coal, and shale. Bedrock outcrops are uncommon. The Wisconsinan Episode impacted the Glaciated Wabash Lowlands Level IV ecoregion, while all three ecoregions were influenced by the earlier Illinoian Glacial Episode. The topography is, for the most part, relatively gentle because of the thick glacial sediment cover.

These three ecoregions—the Glaciated Wabash Lowlands, the Wabash River Bluffs, and Low Hills—form a transition zone between forest and prairie. However, lowland and upland forests dominate the landscape, containing a great diversity of trees: Beech (*Fagus grandifolia*) and Tulip Popular (*Liriodendron tulipifera*), Cottonwood (*Populus deltoides*) and several species of oak —Pin (*Quercus palustris*), Overcup (*Q. lyrata*), Cherrybark (*Q. pagoda*), Bur (*Q. macrocarpa*), Shumard (*Q. shummardii*) and Swamp White (*Q. bicolor*) oaks, as well as Sycamore (*Platanus occidentalis*) and Silver Maple (*Acer saccharinum*), grow along stream banks. The understory includes many spring ephemerals with a nearly continuous cover of forest vegetation. In addition to a large number of tree species, the state's only National Wild and Scenic River, the Middle Fork of the Vermilion River, is found here with several species of fish found no where else, including the Bluebreast and the Harlequin darters.

South of East St. Louis, the Mississippi River bluffs demarcate the western boarder of the **Karstic Northern Ozarkian River Bluffs** (Fig. 2.7q), and, beginning somewhat south of Ava, Illinois, the **Southern Ozarkian River Bluffs** (Fig. 2.7r). Both of these are Level IV ecoregions within the Interior River Valleys and Hills Level III ecoregion. This sliver of landscape is part of the Ozark Uplift, a domelike geologic structure of exposed, ancient bedrock centered in the Ozark Mountains of Missouri and northern Arkansas. Great limestone bluffs mark the edge of the Mississippi Valley (Fig. 2.11). Sandstone ravines of Randolph County and the sinkhole region of Monroe County with its caves and springs make this landscape unique in Illinois. The Karstic Northern Ozarkian River Bluffs were glaciated during the Illinois Episode, and are mostly underlain with relatively pure limestone in the north, but further south with sandstone. The Southern Ozarkian River Bluffs is unglaciated and underlain with cherty limestone.

Figure 2.11. A large limestone bluff found in Union County, Illinois. These bluffs mark the edge of the Mississippi River Valley. Photo by M. Jeffords.

Prior to settlement most of the land in these two Ozarkian ecoregions was forested and a rich assemblage of tree species can still be found here. Shortleaf Pine occurs naturally, and hill prairies are found on the Karstic Northern Ozarkian River Bluffs. Unique organisms include the Eastern Coachwhip Snake, which prefers the seasonally dry, rocky, wooded hillsides and the Plains Scorpion that hides by day amid the crumbling limestone.

Forming the southwestern border of the Interior River Valleys and Hills Level III ecoregion is the **Middle Mississippi Alluvial Plain** Level IV ecoregion (just west of Fig. 2.7r), corresponding to the Lower Mississippi River Bottomlands Division of Schwegman et al. (45). The Mississippi River is muddy here due to the silt load brought in by the Missouri River. The soils have developed from this alluvium and are either coarse or finely textured and relatively well drained or clayey with poor drainage.

To the north, this Level IV ecoregion contains a montage of swales, backwater lakes, sandy ridges, and river terraces. When Charles Dickens visited the area in 1842 all he could hear was the loud coaking of frogs and all he could see on the "unwholesome, steaming earth" was mud, mire, brake (overgrown marshland) and brush. Historically, prairies, marshes, and forests in the north of this Level IV ecoregion gave way to densely forested bottomlands further south.

Still further south, the southernmost units of the Interior River Valleys and Hills nearly encircle the sloping knolls and ridges of the **Cretaceous Hills** Level IV ecoregion (Fig. 2.7s), which breaks up the broad plain of alluvium, making up the southern unit of the **Wabash-Ohio Bottomlands** Level IV ecoregion (Fig. 2.7p). Here in the Wabash-Ohio Bottomlands, forests have not only Pin, Overcup, and Cherrybark oaks but also species associated with bottomland swamps. The Cretaceous Hills form a narrow band from near the Mississippi to the Ohio River. They are low hills made of gravel, sand, and clay and are remnants of the more broadly spread Cretaceous deposits in Kentucky and Tennessee. The hills are low and contain many seep springs. Plants similar to species associated with northern bogs can be found here, including sphagnum moss and a profusion of ferns.

INTERIOR PLATEAU

Just south of where the Illinois Episode glacial margin stopped lie the massive escarpments of the Shawnee Hills, which make up the Interior Plateau Level III ecoregion (Fig. 2.7), but cover only 2.4% of the land area of Illinois. This Level III ecoregion, divided into two Level IV ecoregions, the **Northern and Southern Shawnee Hills** (Figs. 2.7t & u, respectively), which roughly correspond to the Greater and Lesser Shawnee Hills sections of Schwegman et al. (45).

The Interior Plateau is characterized by high, east-west sandstone cliffs that form the Northern Shawnee Hills Level IV ecoregion. Lower hills underlain by limestone and sandstone make up the Southern Shawnee Hills Level IV ecoregion. The topography is very rugged, with many bluffs and ravines. Clear, rocky streams widened and deepened the

ravines, forming canyons, shelves, steps, caves, and shelter bluffs. Where the slopes are steep, bare rock is exposed.

Most of the Interior Plateau was forested at the time of settlement, yet openings occurred, called barrens and glades, a few examples of which can still be found in the Shawnee Hills. Barrens are grassy openings found on rocky, south facing slopes that have only a thin layer of soil. Vegetation includes small, gnarled and twisted Blackjack and Post oaks, prairie grasses, and the occasional Blazing Star. Glades are open expanses of bedrock on bluff tops dominated by Red Cedar. Although prairie grasses such as Little Bluestem occur, the ground is likely to be covered with moss and lichens. The agricultural activity which has so profoundly altered the landscape of the Central Corn Belt Plains and Interior River Valleys and Hills has generally been less intensive in the Interior Plateau, perhaps due to the rugged terrain and poor quality soils—as a result, large tracts of forests and sinuous, clear, rocky streams are common through this ecoregion.

MISSISSIPPI ALLUVIAL PLAIN

The Mississippi Alluvial Plain (Fig. 2.7) is by far the smallest of the six Level III ecoregions in Illinois, accounting for less than 0.2% of the states' land area. It occupies only the extreme southern tip of Illinois, in the southern portions of Pulaski and Alexander counties, where the Ohio and Mississippi rivers converge near Cairo. This ecoregion, and its single Level IV ecoregion—the **Northern Holocene Meander Belts**—corresponds to the southernmost portions of the Coastal Plain of Schwegman et al (45).

The Mississippi Alluvial Plain of Illinois resembles lands that surround the present-day Gulf of Mexico, with swamps of Bald Cypress (*Taxodium distichum*) and Water Tupelo (*Nyssa aquatica*) occurring here near their northernmost limits (Fig. 2.12). Horseshoe Lake State Park contains a large oxbow lake (a U-shaped meander of a river which has become cut off from the river channel, creating a lake) and is representative of this ecoregion.

CLIMATE

The biological landscape of Illinois is shaped in part by its varied climate. From the junction of the Ohio and Mississippi rivers in the south, to the Wisconsin border in the north, the state spans almost 380 miles, and, consequently, climate varies dramatically. Temperatures in Chicago generally stay below freezing throughout most of the month of January, with lows typically below freezing from late November through mid-March (Fig. 2.13), whereas in the far south, at the junction of the Ohio and Mississippi rivers, low temperatures below freezing are mostly restricted to the months of December through February, and the normal high temperatures, even in the coldest part of January, are usually above 40 °F (Fig. 2.13). Concurrent with these marked differences in temperature regimes across the state are differences in precipitation—the southern tip of Illinois receives an average of over 48 inches of precipitation per year, whereas the northern border of the state averages under 36 inches (Fig. 2.14). Environmental conditions, such as temperature, humidity, rainfall, soils and a variety of other factors have a profound influence on ecological communities—the plants and animals inhabiting the ecoregions of Illinois.

Figure 2.12. Cypress-Tupelo swamps are a rare habitat type in Illinois and occur in the Mississippi Alluvial Plain in the extreme southern portion of the state. Photo by Michael Jeffords, INHS.

ECOLOGICAL COMMUNITIES

As a result of the geological history and large latitudinal climatic range, Illinois has a wide variety of natural ecological communities. Natural communities — groups of organisms that are interrelated with each other and their environment — are classified by considering many natural features and choosing the dominant features to identify, name, and describe the communities (51). Nine community classes are recognized in Illinois —forest, prairie, savanna, wetland, lake and pond, stream, primary, cave, and cultural. These communities can be further subdivided, based on physical factors such as soil, slope, moisture, and climate; on biological factors such as the availability of plants and animals adapted to a site's conditions; and on cultural/natural forces such as grazing and fire (52). The following section introduces ecological communities of the state, many of which are discussed in more detail in subsequent chapters (e.g., see Chapter 4 – prairies, forests, savannas, and wetlands).

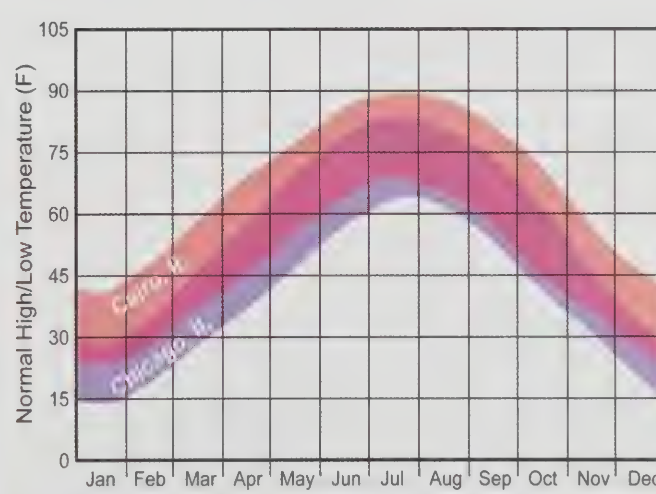

Figure 2.13. Comparison of normal high and low temperatures (degrees Fahrenheit) throughout the year in northern Illinis (Chicago O'Hare airport) and extreme southern Illinois (Cairo, Illinois).

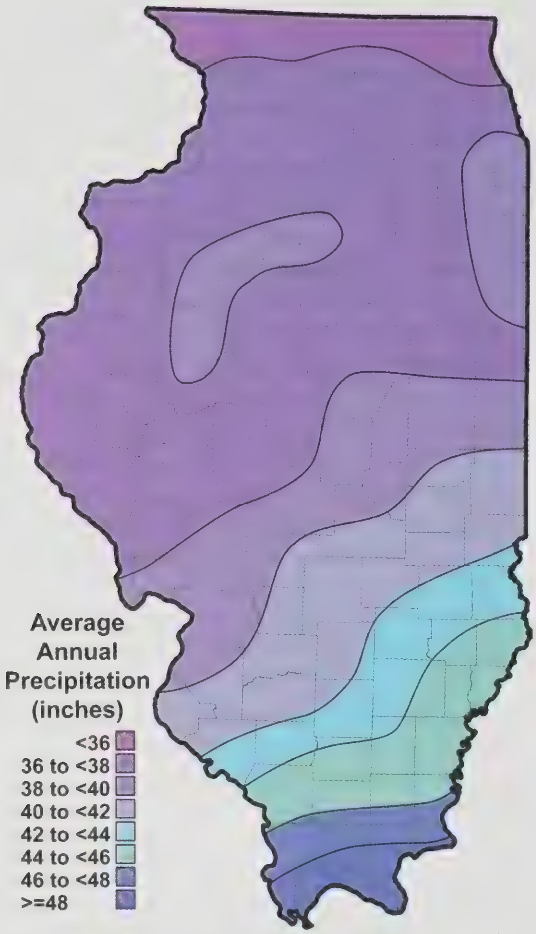

Figure 2.14. Average annual precipitation in Illinois (modified after Changnon et al. [37]).

WETLANDS

Wetland describes land where the water table is at or near the surface, the soils are hydric, and they are occupied by plant species adapted to life in water or saturated soils. The subclasses are marsh, swamp, bog, fen, sedge meadow, panne, and seep and spring. These are recognized mainly by differences in vegetation.

Marshes are characterized by having water at or near the surface during most of the growing season. They are dominated by emergent plants. Water depth in marshes ranges from zero (saturated soil) to perhaps six feet.

Swamps are wetlands where woody vegetation is dominant. Two communities are recognized. Swamps are limited to southern Illinois, because only southern tree species can live in permanent bodies of water. Shrub swamp has at least 50% coverage by shrubs and occurs throughout the state.

Bogs are usually found in glacial depressions with restricted drainage and can become acidic. Carbon dioxide accumulates in the water and inhibits the growth of decomposer organisms. Decomposition is reduced in a bog, and large quantities of dead plant life accumulate in ever-thickening layers to form peat. A layer of *Sphagnum* characterizes nearly all bog communities. Bogs may be grassy or forested, or have tall or short shrubs.

Fens are a type of wet meadow fed by alkaline water, usually from a spring or a seep. They occur on organic soils and can be shrubby, grassy, forested or even a calcareous floating mat. Fens are extremely sensitive to disturbance as any change in the groundwater either by pollution or changes in the water table alters the habitat.

Sedge meadows occur on organic soils and sometimes include peat accumulation. They are saturated during much of the year, but are not inundated for long periods. Species diversity is low with sedges the dominant plant.

Pannes occupy the wet and wet-mesic interdunal swales that form in calcareous sand between the dunes along Lake Michigan. They are restricted in Illinois to a one-mile undeveloped zone of Lake Michigan shoreline. This community shares considerable floristic overlap with graminoid fen and calcareous seep communities (53).

Seeps are wetland communities characterized by a constant, diffuse flow of groundwater. They may be acidic or basic, depending on the materials through which the groundwater flows before reaching the surface. Seeps are common along the edges of moraines, ravines, and terraces where the groundwater meets a layer of material impervious to its downward movement. As a result, the water flows outward over a wide area until it reaches the surface, often at the base of a bluff or in a ravine. In Illinois, five different seep community types are recognized—seep, acid gravel seep, calcareous seep, sand seep and spring. Spring communities occur when a channel is formed.

LAKE AND POND

Illinois contains more than 91,000 lakes and ponds, totalling more than 253,000 acres of inland waters, including about 3,256 lakes with a surface area more than 6 acres (54), the largest being Carlyle Reservoir, with an area of about 26,000 acres (55). Of course, Lake Michigan, along Illinois' northeastern edge, is far larger than any of these (about 14,336,000 acres), and though only 63 miles of its shoreline abuts the state, Illinois has jurisdiction over about a million acres of Lake Michigan [54], and it contributes significantly to the states' biodiversity. In addition, many smaller ponds are scattered across the state. Many ponds and lakes in the glaciated portions of northeastern Illinois are natural "kettle" lakes, forming as a result of the melting of ice blocks which had been buried under glacial deposits. Oxbow lakes (e.g., Horseshoe Lake in southern Illinois, just over 2,000 acres) and backwaters along major rivers are also natural in origin, forming when rivers change course, and in karst areas sinkhole ponds that dot the landscape. However, the majority of Illinois lakes and ponds are made by humans—these include artificial impoundments (dams) on rivers and streams, excavated farm ponds, strip mine lakes, and borrow pits.

Lakes and ponds are open, standing bodies of water. Ponds are small, nonseasonal bodies of water less than 20 acres in size and are shallow enough to allow rooted aquatic vegetation across much of the surface area. All ponds in Illinois are rich in dissolved nutrients, shallow, and seasonally deficient in oxygen. Lakes are larger (greater than 20 acres), deeper, where wave action usually produces a semi barren, wave-swept shore, and portions of the lake are too deep to support rooted aquatic plants. There are two lake classes—lake and great lake.

STREAMS AND RIVERS

Streams are natural communities with permanently flowing water throughout the year and have been classified by White and Madany (51) as Creek and River subclasses. Creeks are distinguished from rivers by having watersheds less than 200 square miles (520 sq. km.). The individual natural communities within the subclasses are described according to gradient and size—low, medium, and high.

Streams and rivers also form a major part of Illinois's landscape and, importantly, their riparian boarders make up a significant portion of the remaining wooded habitat in much of the state. Some 87,110 miles of streams and rivers (54) dissect the Illinois landscape, and dominant among these are the Illinois, Kaskaskia, and Sangamon rivers. In addition, Illinois' boarders are dominated by three rivers: the Mississippi River, boarding the state to the west, and the Wabash and Ohio rivers on the eastern and southern sides of of the state—these three border rivers comprise an additional 1,089 river miles (54). While Illinois' flowing waters are nearly all natural (exceptions include Post Creek Cutoff of the Cache River, in southern Illinois), many of the smaller streams, and even some rivers, have been drastically altered because of channelization carried out to provide drainage for farmlands.

Drainage of wetlands, siltation of impounded river reaches, and erosion—all resulting from increasing development on major rivers in Illinois and elsewhere in the Midwest—have been recognized at least since the 1930s as potential problems caused by the encroachment of civilization, locks and dams, and land clearing for agricultural purposes (56). To this day, sedimentation in major rivers resulting from a series of interrelated factors including erosion and the establishment of the lock and dam system in the mid 1900s, continues to challenge federal and state agencies as well as biologists (e.g., 57).

GROUNDWATER

Illinois' groundwater plays an important role in biological systems in many portions of the state. In central Illinois, the Mahomet Aquifer is of great value as a drinking water source for many central Illinois communities. The aquifer resides in the buried Mahomet Bedrock Valley, and in places is up to 200 feet thick and up to 14 miles wide (58). The drinking water for Illinois' rural population comes mostly (90% [59]) from groundwater, and most of that is from limited, shallow (<50 ft) sources.

More clearly evident in their impact on plant and animal life in Illinois, though, are the shallow groundwater conduits found throughout Illinois' four major karst regions, comprising about a fourth of Illinois' land surface (60). The karst groundwater flows quickly, is influenced by rainfall and snowmelt, and harbors unique life forms, including the federally listed endangered Illinois Cave Amphipod (Gammaridae: *Gammarus acherondytes*), and a state listed endangered snail, the Enigmatic Cavesnail, (Hydrobiidae: *Fontigens antrocetes*). These "subterranean streams" emerge on the surface, typically as springs, where their cool waters and relatively constant temperatures provide a habitat for unique faunas.

FOREST

Forest communities include lands that are dominated by trees, with an average canopy cover of 80% or greater. There are four subclasses of forests—upland, sand, floodplain, and flatwoods (51).

Upland forests usually do not flood and contain communities that are defined by soil moisture classes—xeric to wet-mesic.

Sand forest communities occur in areas of sand deposits where natural firebreaks have reduced burning frequency. These, too, are defined by soil moisture—dry to mesic.

Floodplain forests occur along streams and rivers. They have poor soil drainage with slow permeability. Because these forests are flooded frequently, they have a lower diversity of tree species than forests on higher ground. They are further separated by soil moisture class—mesic or wet.

Flatwoods occur on level or nearly level ground. The soil is nearly impermeable, usually a clay layer, that causes a shallow, perched water table. Organisms must adapt to being seasonally wet to bone dry. Due to the fluctuation of moisture, the moisture class is not in the community names of northern, southern, and sand flatwoods.

PRAIRIE

Prairies are treeless grasslands dominated by warm-season grasses and forbs. Trees cover less than 10% of the area. Six prairie subclasses are recognized in Illinois: prairie (tallgrass prairie on silt-loam soils), sand prairie, gravel prairie, dolomite prairie, hill prairie, and shrub prairie (51). Further divisions are made based on soil moisture or substrate classes, yielding 23 prairie types in Illinois.

The prairie subclass includes the typical black-soil prairies on deep, fine-textured silt-loam or clay-loam soils formed in loess, glacial till, or sometimes alluvium. These prairies are often referred to as **tallgrass prairies** due to the dominance of the tall grasses Big Bluestem (*Andropogon gerardi*) and Indian Grass (*Sorghastrum nutans*). Soil moisture for these prairies ranges from dry to wet.

Sand prairies are found on course textured soils such as sand, loamy sand, and sandy loams. They are found on outwash plains, lake plains, and outwash terraces where the soil moisture varies from dry to wet.

Gravel prairies are found on gravel or gravelly soil where the gravel provides rapid permeability. These prairies occur on valley train deposits, kames, eskers, and on the slopes of gravel terraces along major rivers. The soil is calcareous and the moisture classes range from dry to mesic.

Dolomite prairies are found where dolomite bedrock is at or near the surface. The soil has high pH and is shallow. These prairies are very localized and occur where glacial meltwaters have washed away much of the overlying till leaving a thin layer soil (sand or gravel) over the dolomite. Moisture classes range from dry to wet.

Hill prairies on the windswept bluff tops along Illinois major rivers are treeless areas covered with prairie plants. They occupy the upper west- to south-facing slopes of bluffs above the river floodplain below. The classification of hill prairies is based on soil type rather than moisture.

Shrub prairie is characterized by the co-dominance of shrubs and prairie grasses. Mosses form a continuous ground layer. This community is limited to northern Illinois.

SAVANNA

Savannas are characterized by scattered, open-grown trees, with or without shrubs, and a groundcover dominated by grasses, sedges, and forbs. A savanna is an intermediate community between prairie and closed woodland, with canopy cover less than 80%, but greater than 10%. Savannas have several characteristics—an open-canopied structure, canopy dominance by oaks, ground cover rich in tall grass prairie species which supplies the floristic diversity, and dependence on fire for maintenance and stability (61). There are three savanna subclasses—savanna, sand savanna, and barrens. Individual savanna communities are distinguished by soil moisture class.

The typical **savanna** community subclass occupies fine-textured soil on till plains. They occurred as islands in prairie or forest and on extensive areas of hilly land. Two natural communities based on soil moisture are recognized—dry-mesic and mesic. Mesic savannas are among the rarest plant communities in the Midwest.

Sand savannas occur on soils that are very sandy and with little humus and are associated with dune and swale topography, either dunes or beach ridges. The undulating topography limited the severity of fires and allowed a savanna to develop instead of a sand prairie. There are two sand savanna communities—dry and dry-mesic.

In Illinois a **barrens** community refers to local inclusions of prairie flora, mixed with forest, occurring in southern and western Illinois forested land and along major rivers. These were areas that were of limited use for agriculture. Three communities are separated in soil moisture classes—dry to mesic.

PRIMARY

Primary communities are associated with outcroppings of bedrock and include glade, cliff and lake shore. Glades are local areas in forest where bedrock is at the surface. Vegetation is often sparse with large areas of bedrock exposed. While glades are usually fairly level, they are found on dry to xeric exposures with south- or west-facing exposure. Glades are defined by their rock type—sandstone, limestone, or shale (51). Cliffs are vertical exposures of bedrock and can range from a few feet to about 300 feet high in Illinois. Soils are usually nonexistent and communities are again defined on the basis of the rock type—sandstone, limestone, dolomite, sandstone overhang, and eroding bluff (51)

SUMMARY

As a part of planning future management and research agendas, scientists and land managers interpret biological changes through time in the context of the landscape. Illinois has a surprisingly diverse landscape, not immediately obvious if one just passes through the state on Interstate highways. The 25 Level IV ecoregions contain numerous community types and unique combinations of climate, geological history, and soils. It is in the context of this landscape that we can come to study, understand, and appreciate the biota of Illinois.

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CHAPTER 3

Biological Change Detection: Methods and Applications

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OBJECTIVES

How are biological changes detected and measured? This chapter introduces Part II of *Canaries in the Catbird Seat*, a section focusing on biotic changes, and examines some of the principal methods employed for assessing these changes. Featured will be standard tools and methods for a variety of biological groups, the role of computer-based Geographic Information Systems, and a far-sighted monitoring effort known as the Critical Trends Assessment Program.

INTRODUCTION

Biological changes occur over a wide range of time scales. Long-term changes can be at a geological time frame such as following Pleistocene glaciation about 14,000 years before present or historical such as the settlement by Euro-American pioneers in the early 1800s. More contemporary changes can range from decades to more short-term seasonal trends. This chapter explores the different methods used for measuring changes over these different time frames. Methods include analysis of pollen grains in ancient lakebed and peat deposits for understanding long-term vegetation trends to applications of modern Geographic Information Systems (GIS) and the Critical Trends Assessment Program (CTAP). GIS and CTAP are highlighted here as methods for detecting historical and ongoing biological changes. Modeling future changes resulting from global climate warming is addressed in Chapter 16 in Part III of this volume. Evolutionary changes, such as in the morphology and ecology of taxonomic groups, can occur over very long time spans (e.g., in some cases hundreds of thousands of years) and are beyond the scope of the considerations of this chapter.

LONG-TERM CHANGE DETECTION

POST-PLEISTOCENE CHANGES

An example of biological change at a geological time scale is the pattern of vegetation change since the last glacial period. Knowledge of these long-term changes is key to understanding modern species distributions and particularly is relevant to putting into perspective ongoing trends, especially with regard to global climate warming. Studies of long-term changes typically include palynological analyses where pollen content preserved in buried peatland or lakebed deposits, or strata, is examined. Palynology is a branch of paleoecology and involves the study of fossil pollen grains. Peatlands formed since the late Pleistocene, and some lake beds, can provide a sequential catalog of regional vegetation changes in the pollen content occurring at different strata in the deposit. Pollen grains have characteristics in shape and surface that enable scientists to determine the dominant genera and species that were present in former times. Advantages of palynological analyses are that the deposits represent a relatively broad geographic area since pollen from many species can arrive on winds from distant locations, in contrast to whole plant or animal fossil evidence which provides information mostly at a localized scale. However, primarily only wind-dispersed pollen is found in the peat and lake deposits while pollen grains of species dispersed by insects tend to be scarce or absent. Nevertheless, pollen analyses have revealed the broad chronosequence of vegetation changes that occurred from the end of the Pleistocene to current times (1, 2, 3). These changes are outlined in Chapter 4.

CHANGES SINCE EURO-AMERICAN SETTLEMENT

The resolution of biological changes since Euro-American settlement depends greatly on the available data. Data from the early years of post-settlement are limited and, with the exception of the Government Land Office surveys (see below), largely anecdotal. In Illinois, specimens housed in museum collections generally only became part of the biological record about the time of the beginnings of the Illinois Natural History Survey (INHS) in the latter half of the nineteenth century. The capacity for detecting historical changes has increased dramatically during the past 70 years when standardized statewide coverage of aerial photography became available. For example, detection of changes in extent of hill prairies has been made feasible by comparing aerial photographs taken at different time periods (see Chapter 4, Prairie section). Detecting ongoing changes can be done much more precisely with biological monitoring programs designed for detecting the changes of interest, or through experimental studies, by measuring response to a particular treatment as part of an experimental design.

In the early part of the nineteenth century, the Government Land Office (GLO) carried out the Public Land Surveys establishing the grid coordinate system for Township, Range, and Section lines (4). One of the most fortuitous decisions in shaping our understanding of the patterns of vegetation composition throughout the Midwest at the time of the first Euro-American settlements was the recording of land cover characteristics in the survey methods. These data form the basis for understanding the presettlement distribution of prairies and forests in Illinois (see following section on GIS) and provide a vital baseline against which changes from nearly 200 years of post-Euro-American settlement can be compared.

The first comprehensive forest survey in Illinois, conducted from 1921 to 1924, summarized information on changes in forest cover during the late nineteenth century and the beginning of the twentieth century (5). These data provide an important benchmark for the distribution and composition of forests at a time just following a period of major deforestation and prior to gradual reforestation. These data are used to understand trends in forest type and forest land cover statewide (see Chapter 4, Forest section). Data on the distribution of tree age and size classes from forest stand samples provide a means to evaluate tree species regeneration patterns. Such patterns have been instrumental in characterizing widespread failure in oak recruitment and have provided examples of the maple take-over phenomenon. The Forest Inventory and Analysis (FIA) program of the U.S. Forest Service is a key component to understanding forest trends since the original Telford (5) survey. There have been five major sampling cycles since Telford (1948, 1965, 1985, 1998, and 2005) by the FIA program utilizing up to 1,209 forest sample points distributed throughout Illinois (6).

Specimen records and databases from museum collections provide details on the distribution patterns for a wide range of species and can be used for tracking changes at different spatial scales (e.g., 7, 8, 9, 10, 11, 12). Results from comprehensive biotic surveys in the past provide a means to make time-based comparisons on species diversity and composition at specific locations, particularly where specimen vouchers were collected. For example, identifying trends for when and where invasions of non-native species began often can be made with such collections data.

Annual bird counts coordinated by local chapters of the National Audubon Society, conducted throughout North America during winter and breeding season, have provided a robust dataset for understanding changes in avian communities (see Chapter 6). Hunting records also provide information for game species and some clues to long-term trends. Characterizing trends for nongame invertebrate and vertebrate species mostly hinges on repeated surveys. For example, understanding the dramatic changes in fish or mussel populations throughout Illinois streams and lakes has been possible only through comparison of statewide surveys conducted over many years (see Chapters 9 and 10). Even road kills provide clues to biological changes. Evidence for the recent immigration of Nine Banded Armadillos into Illinois mostly has been possible through records of roadside carnage (Fig. 3.1) throughout the southern counties (13, 14).

One of the most effective modern tools for detecting landscape-level changes involves the use of Geographic Information Systems (GIS) technology for analyzing a wide variety of data sets, including satellite imagery. Examples of GIS applications to understanding biological changes are described in detail below. Finally, there is no substitute for data from long-term monitoring for understanding with precision the nature of biotic changes. Such monitoring takes foresight and anticipates future needs for understanding changes in biological resources. The monitoring phase of the Critical Trends Assessment Program examines trends for insects, birds, and vegetation throughout Illinois in forest, grassland, wetland, and stream habitats and is a prime example of valuable foresightedness (see section in this chapter on CTAP).

Figure 3.1. A Nine Banded Armadillo (*Dasypuss novemcinctus*) in the east-bound shoulder of I-70 in Bond County, Illinois. An example of a new mammal entering Illinos from further south. Photo by J. Hofmann.

GEOGRAPHIC INFORMATION SYSTEM

HISTORY OF GEOGRAPHY AND GEOGRAPHIC INFORMATION SYSTEMS (GIS)

The science of geography has been around for centuries. As a discipline, geography combines aspects of natural and social sciences. With the advent of computers, the science and application of geography has greatly expanded beyond the experience of learning names of countries, state capitals, and the longest rivers. The following section outlines computer-based geographic information systems (GIS) and how they can be used in a variety of fields. In the natural sciences, GIS has become a central tool used for modeling and tracking changes among biological resources, particularly at the landscape scale.

Beginning with weather mapping in the 1950s, computer-based mapping tools have become more powerful and commonplace. GIS was first developed in the 1970s and it has helped scientists to combine spatial information from many sources, allowing for fast analysis, modeling, and powerful displays of information. GIS is being used in such diverse fields as law enforcement and emergency services, ecology, forestry, agriculture, natural resource conservation, and urban planning. GIS technologies are applied by universities, state and federal agencies, nonprofit organizations, and businesses worldwide. Anyone using on-line mapping programs to get travel directions or viewing maps presented in news programming has experienced the products of GIS.

WHAT IS GIS?

GIS is a type of computer software used to gather, store, analyze, and display geographically referenced information. GIS data are stored in layers. For example, one layer might

consist of property boundaries, another of roadways, and another of biological sampling locations. If these data are represented as geometric objects, lines, points, and polygons, these are referred to as vector data. Another way of storing GIS data is as raster data. To envision raster data, think of a grid lying over the landscape. Each cell or pixel of the grid has a unique coordinate, or value. This is how raster data are stored. Raster data are most often used to store aerial photos, satellite images, or elevation information. The most common way of getting raster data into a GIS is by electronic scanning and then converting the image or data into the grid of cells. Vector data are usually created by digitizing or tracing information in the GIS software, often using the electronically scanned information as a source, or by collecting the information with a GPS (Global Positioning System) unit. Today, many types of data are available for use in a GIS, some for purchase, and some free through federal, state or local agencies. Vector data and raster data can be combined in GIS layers presenting information such as county boundaries, vegetation land-cover classes, and satellite imagery (Fig. 3.2).

MAP PROJECTION, SCALE, AND RESOLUTION

In order for data to be used with GIS software, they must be "registered" or have spatial information. This is done by defining a spatial reference coordinate system. One of the most recognizable registration systems is longitude and latitude. Once the data are in a spatial reference system, the GIS software can manipulate them through mathematical conversions into a projection system. A map projection is simply a way of converting the three-dimensional, curved surface of the Earth into a two-dimensional system that can be displayed on a piece of paper or computer screen. There are many projection systems. Some are best at representing shapes accurately, some represent relative sizes or map features better. Some map projections are better for world maps, some for countries, and some for individual states. Whichever map projection is chosen, all the data in a GIS must be in the same map projection in order to be used for analysis and display. Once the original map projection has been defined for each individual data layer, the latest versions of GIS software will convert all data layers to the same map projection automatically for proper map display.

Another important consideration for GIS work is map scale and resolution. Since it is impractical to represent the world at a 1:1 scale, all maps represent a scaled down version of the Earth's surface, one that better fits on a piece of paper or a computer screen. Map scale refers to the ratio of the distance on the map to the equivalent distance on the ground. This is often expressed as a fraction. For example, 1/25,000, sometimes written as a ratio (1:25,000), means that one unit on the map represents 25,000 equal units on the ground. Typical units are miles, kilometers, meters, or feet. Some standard map scales are 1:10,000, 1:25,000, 1:50,000, 1:100,000, 1:250,000, and 1:500,000. Maps often are referred to as "large scale" or "small scale." A large-scale map displays features so they appear large. For example, the boundary of a town on a 1:10,000 scale map would appear larger and show more detail than the same town displayed on a 1:100,000 scale map.

Map resolution refers to the minimum size a feature can be clearly represented or how clearly items on a map can be differentiated. When data are created with GIS software from a data source, the amount of detail present depends on the map resolution of the original source and the quality of data capture. This idea can be illustrated with the following examples of mapping presettlement vegetation in Illinois.

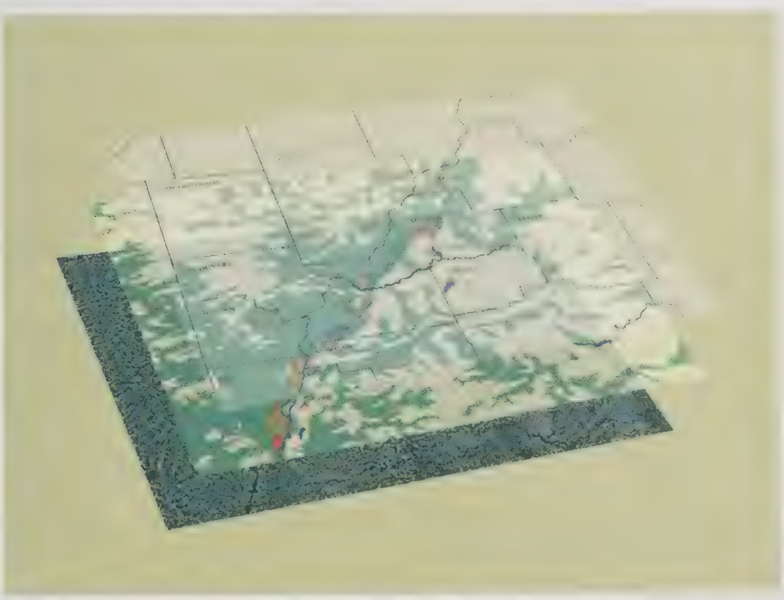

Figure 3.2. Example of layered information that can be analyzed using Geographic Information Systems (GIS). Shown are three layers (2 vector, 1 rastor): the top layer is county boundaries, the middle layer presents vegetation land-cover classes, and the bottom layer is an aerial photograph. Any combination of these data layers can be presented. Additional data layers can be included such as field sample locations or distribution patterns for particular plant or animal species.

LANDCOVER MAPPING

PRESETTLEMENT VEGETATION MAPS

The first map of prairie in Illinois was by Gerhard (15), as drawn by Barrows (16). This map (Fig. 3.3a) also was published in Sampson (17). A more detailed map of the prairie-forest boundary (Fig. 3.3b), based on soil survey maps (a more detailed data source), was created by Vestal (18). These two maps were reprinted in Anderson (19).

Anderson (19) compared the amount of prairie shown in these two earlier maps with the one he created using another source of information. In the 1850s the Surveyor General's office in St. Louis, Missouri, created township maps of the land cover for Illinois. These maps were based on field notes and maps drawn by the surveyors during the Government Land Office (GLO) surveys conducted concurrently with the first permanent Euro-American settlements in the state. Today, the original plat maps are housed at the Illinois State Archives in Springfield, Illinois.

In the 1960s, microfilm copies of these maps were created, and distributed to many university libraries around Illinois. In 1970, before GIS software was widely available, Anderson (19) created a map (Fig. 3.3c) by viewing the microfilm and transferred

the vegetation data from the microfilm onto a paper map where each township was "drawn in approximately one-half inch squares" (1:125,000 map scale). This map indicated that about 40% of the land cover in Illinois at the time of the GLO surveys was forest and from that estimate, it was assumed that about 60% of the land was prairie (20).

In the 1980s, researchers were interested in determining the area of forest in Illinois during the early 1800s (21). They used Anderson's 1970 map as a base, but updated the prairie, forest, and wetland categories for 37 selected counties. The original survey maps from the microfilm were again used for the update, but each township was printed at about 12 x 12 inches. These maps were digitized by tracing the lines using a digitizing table attached to a computer, and the digitized version was geo-referenced (a process of assigning real world coordinates to the scanned image) with the GIS software. Since these data were created using digital maps with a higher resolution, the information created with this process has a 1:64,000 map scale (Fig. 3.3d). Results of this effort suggested that about 38.2% of the state was forest (21).

In 2002, a new version of these data was created (22). In this version, all land cover categories as drawn on the original survey maps were digitized, not just forest and prairie. The microfilm versions of the survey maps were again used; however, for this effort the map images were scanned directly into a computer. These scanned versions were geo-referenced, then digitized. This provided a means to zoom in closer to the information and more accurately represent the data, resulting in a map scale of about 1:24,000. As a result of improved technologies, the map scale of the resulting data also improved. In Figure 3.3e, the prairie-forest boundary is shown in black and white for comparison with the earlier versions. In this revised presettlement land cover, forest is estimated to have been 42% of the land area and prairie about 55% with the remainder open-water and wetlands (22). The results of these improved methods lead to an increase in the amount of land cover classified as forest (including some land cover that could be classified as savanna). Twelve of the 42 land use categories digitized in the Szafoni et al. (22) version are shown in color in Figure 3.3f. The improved resolution and additional land cover categories greatly improves the usefulness of the data for regional and local applications.

LAND COVER DATA TODAY

Today, high resolution remotely sensed data are widely available. Satellite data and aerial photos often come already geo-referenced and are easily used in GIS software. In 1995 and again in 2000 (Fig. 3.4), the INHS used satellite data to create a statewide land cover of Illinois map. These land cover data have been widely used by many researchers in a number of scientific disciplines.

DATA ANALYSIS AND HOW GIS IS USED IN ECOLOGICAL RESEARCH

The real power behind a GIS is in the additional tabular data stored in a database linked to the map information. This is how a GIS differs from computerized drafting software such as AutoCAD. By combining the visualization power of a map with the detailed information in a database, a whole new world of analysis is available. Data layers can be combined to see what features overlap; areas can be buffered by different distances to see what occurs nearby; the additional data associated with the spatial locations can be used to ask questions such as "What is at a given location?," "Where does something occur?," "What spatial patterns exist?," and for modeling questions such as "What if…?"

Suppose one wanted to ask the question "Where have changes in extent occurred to forest land cover in Illinois since the early 1800s?" By using the forest land cover category from the Land Cover in Illinois in the Early 1800s vegetation map from Figure 3.3f, and the forest land cover category from the most recent satellite land cover map (e.g., Fig. 3.4), GIS software can be used to overlay the two data sets to derive the answer. Figure 3.5 shows the results of a comparison of the upland and bottomland forests, and swamp lands from the early 1800 and 2000. While the amount of forested areas extant in the 1800s have decreased 6,701,986 acres, an additional 874,650 acres of forest have been added in areas not previously forested (Table 3.1). This type of analysis is readily available with GIS software.

At the INHS, GIS has long been used to create statewide data layers such as presettlement land cover, modern land cover using satellite images (1999–2000), boundaries of public land, natural areas, and nature preserves, and to map plant and animal collection locations. Some additional recent data layers developed at INHS include animal species distribution maps for the National GAP program and accurate boundaries of state-owned, managed, and leased lands from legal descriptions. The INHS also uses GIS to map wetland and other habitat locations in potential road construction sites, related threatened and endangered species locations, and to record changes over time in plant occurrences and distributions. The 2000 land cover data, along with many other statewide data sets, were used in an analysis of habitat quality to create a data layer of Green Infrastructure (23), a prioritization of the best forest, grassland, and wetland areas left in Illinois (Fig. 3.6).

Environmental sciences in general use GIS for modeling, visualization, and analysis. Location information can be used to model animal movement, dispersion, migration, and distribution of species and habitats. Satellite images have been used to track the spread of wild fires and recovery of the land afterwards. GIS has proven to be a powerful tool in many areas of ecology.

Table 3.1. Land Cover totals from comparison of forest and swamp land cover: 1800s and 2000.

Land Cover	Acres
Nonforest	2,203,829
Forested in 1800s	11,001,611
Forested in both 1800s and 2000	4,299,625
Forested in 2000 only	874,650
Total	**18,379,715**

CRITICAL TRENDS ASSESSMENT PROGRAM (CTAP)

THE NEED FOR ECOLOGICAL MONITORING

Natural environments are exceedingly complex and the landscape of Illinois, perhaps despite first impressions, is no exception. Even with the destruction and homogenization of natural habitats due to extensive agricultural and other human development, understanding the complexity of the remaining woodlands, wetlands, streams and grasslands in this state and how these habitats are changing is a necessary step in conserving these resources.

The Critical Trends Assessment Program (CTAP) was started in the early 1990s to evaluate the ecological condition of Illinois using some of the change detection methods described in this chapter. Scientists from the Illinois Natural History, Geological, and Water surveys as well as the Waste Management Research Center worked with personnel from the Illinois Environmental Protection Agency and Illinois Departments of Agriculture, Natural Resources, Mines and Minerals, Nuclear Safety, Public Health, and Transportation to analyze available information about the environment of Illinois (24). Researchers asked, "What human activities have affected forest, stream, river, lake, prairie, wetland, and agricultural ecosystems in Illinois?"

Results from a two-year effort came up with three major conclusions:
1. The emission and discharge of regulated pollutants over the past 20 years has declined, in some cases dramatically,
2. Existing data suggest that the condition of natural ecosystems in Illinois is rapidly declining as a result of fragmentation and continual stress, and
3. Data designed to monitor compliance with environmental regulations or the status of species are not sufficient to assess ecosystem health statewide.

Additionally, INHS researchers concluded: "Although we lack an overall metric of ecosystem health, Illinois ecosystems are greatly affected by human activity, and that effect in general seems to be increasing. This is in spite of many specific improvements and an overall reduction in pollution sources. Often the largest impact is land use, the weight of many pressures on few acres" (24).

SET-UP FOR THE LONG HAUL

From this initial endeavor using the best available information, came the realization that more was needed to be done to determine the status of ecosystems in Illinois. It was obvious that ecosystems were deteriorating as a result of habitat fragmentation and biotic and abiotic stressors. The report resulting from the initial two-year project recommended collecting data statewide to determine current ecosystem condition. In addition, repeated, long-term monitoring of Illinois' native habitats could answer some of the nagging questions about ecological trends.

So in 1997, the monitoring component of CTAP was born. Field biologists were hired to collect plant, bird, and insect data in randomly selected forest (see Chapter 15), wetland, and grassland habitats across the state of Illinois. Data on aquatic insects from randomly selected stream segments also were collected. The main goal of the field component of CTAP was to gather baseline data on the current condition of these four ecosystems. With repeated monitoring, changes over time in these ecosystems also could be assessed. These data could then be used to provide policy makers and land managers much needed information to facilitate efforts to preserve, restore, and manage Illinois' forests, wetlands, grasslands, and streams.

PROJECT DESIGN AND METHODOLOGY

In order to draw statistical inference about the status and trends of bio-indicators at the statewide level, a population of random, independent sampling units was needed. For each habitat class (forest, grassland, wetland, and stream) 150 sites distributed statewide were randomly selected (Fig. 3.8). Thirty sites per habitat were sampled in a given year. After five years, all 150 sites per habitat were sampled and a cycle of re-sampling began in the sixth year of the program.

Land cover information from the GIS database was used to identify potential monitoring sites for each of the habitat types. On-the-ground assessment was then made to determine if a site was suitable for monitoring and to gain landowner permission. Most sample locations occur on private land (Fig. 3.8).

Since it is not feasible to measure all biological components of a habitat, CTAP focuses on representative groups of organisms (plants, birds, and insects) to measure condition and change.

- Plants—ground layer vegetation identified to species and percent cover for each species estimated; woody shrubs identified to species and stems tallied; and over story trees identified to species, stems tallied and diameter measured at each forest, wetland, and grassland site. (See Chapter 15).
- Birds—10-minute point counts with all birds heard and seen recorded at each forest, wetland, and grassland site.
- Terrestrial insects—sweep net used to collect insects in standing vegetation at each forest, wetland, and grassland site; species sorted, identified, and tallied.
- Aquatic insects—benthic samples collected at each stream site; species sorted, identified, and tallied.

For a comprehensive description of CTAP methodology, see Molano-Flores (25).

In addition to randomly selected sites, a small number of high-quality reference sites were selected and monitored to provide benchmarks for comparison with the randomly selected CTAP monitoring sites. This was done with the knowledge that most random sites have been degraded by past disturbances that have altered the natural condition. In Illinois this includes logging, grazing, mowing, drainage of wetlands, herbicide spray, agricultural tillage, and many other factors.

Reference sites were selected for each habitat based on the focus organism. In the case of plants and insects, sites were selected where the vegetation was in a pristine or least-disturbed condition. These sites were often limited to Illinois Nature Preserves or other protected natural areas including sites identified by the Illinois Natural Areas Inventory (INAI). Consequently, a greater proportion of reference

Figure 3.3a. Prairie areas in Illinois in the early 1800s as interpreted by Gerhard (15), and modified by Barrow (16). Map from Anderson (19).

Figure 3.3b. Prairie areas in Illinois in the early 1800s from Vestal's (18) map. Map from Anderson (19).

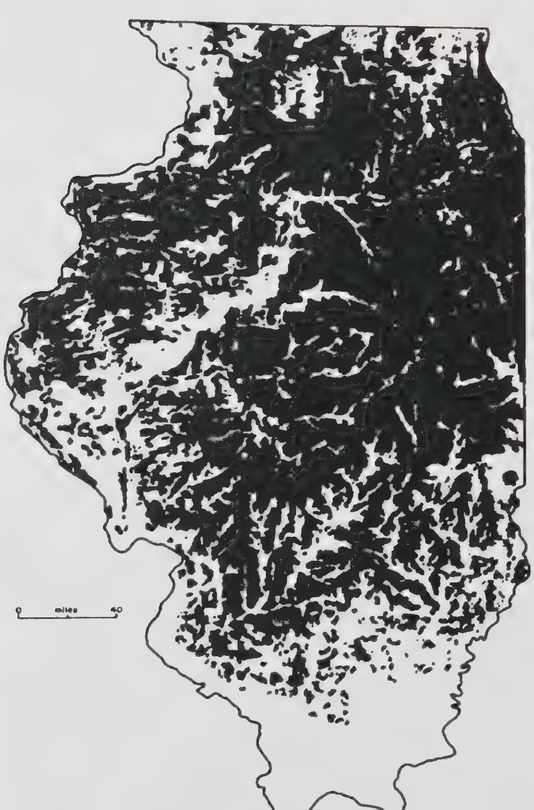

Figure 3.3c. Prairie areas in Illinois in the early 1800s from Anderson (19).

Figure 3.3d. Prairie areas in Illinois in the early 1800s from Iverson et al. (21).

Figure 3.3e. Prairie areas in Illinois in the early 1800s from Szafoni et al. (22).

Figure 3.3f. Color version of Szafoni et al.(22) showing distribution of prairie in the early 1800s with some of the additional categories.

sites, compared with randomly selected CTAP sites, occur on public lands (Fig. 3.10). For birds, large and unfragmented tracts of forest, wetland and grassland were selected with natural vegetation structure capable of supporting breeding populations. Reference streams had relatively clean waters with natural structures such as meanders, deep and shallow pools, and riffles as well as naturally vegetated banks and riparian zones.

Ongoing CTAP monitoring will provide a key insight to trends in the major habitat types in Illinois. Comprehensive monitoring programs such as CTAP are essential to precise evaluations of ecological trends in Illinois habitats. See Chapter 15 for a summary of forest sampling results.

Figure 3.4. Illinois land cover in 2000.

Figure 3.5. Comparison of forest and swamp land cover: early 1800s and 2000.

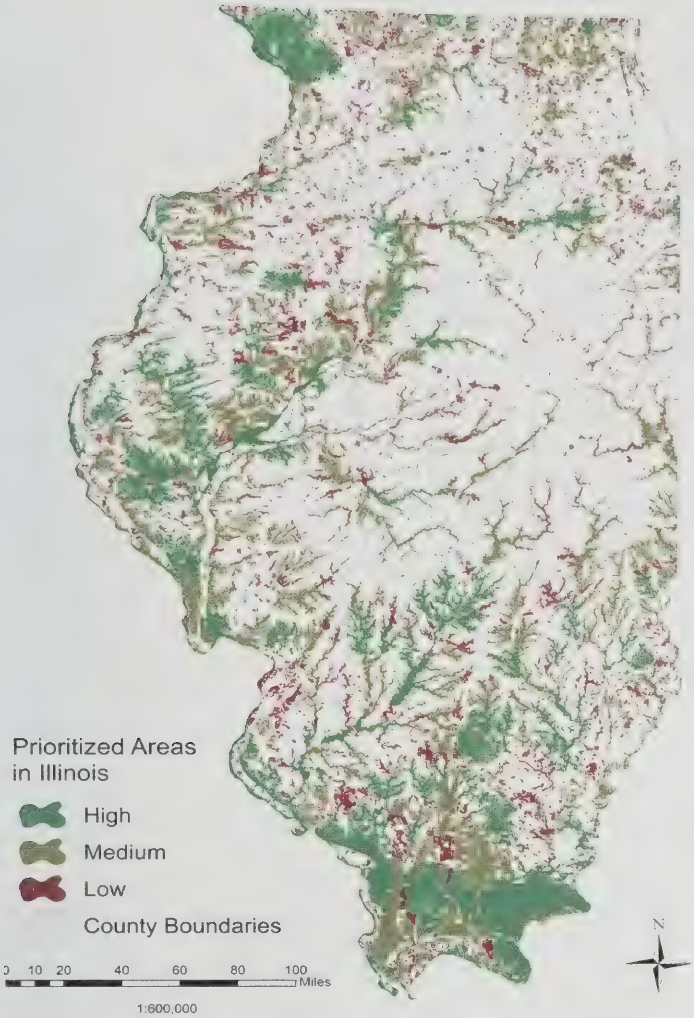

Figure 3.6. The prioritized Green Infrastructure areas in Illinois (23).

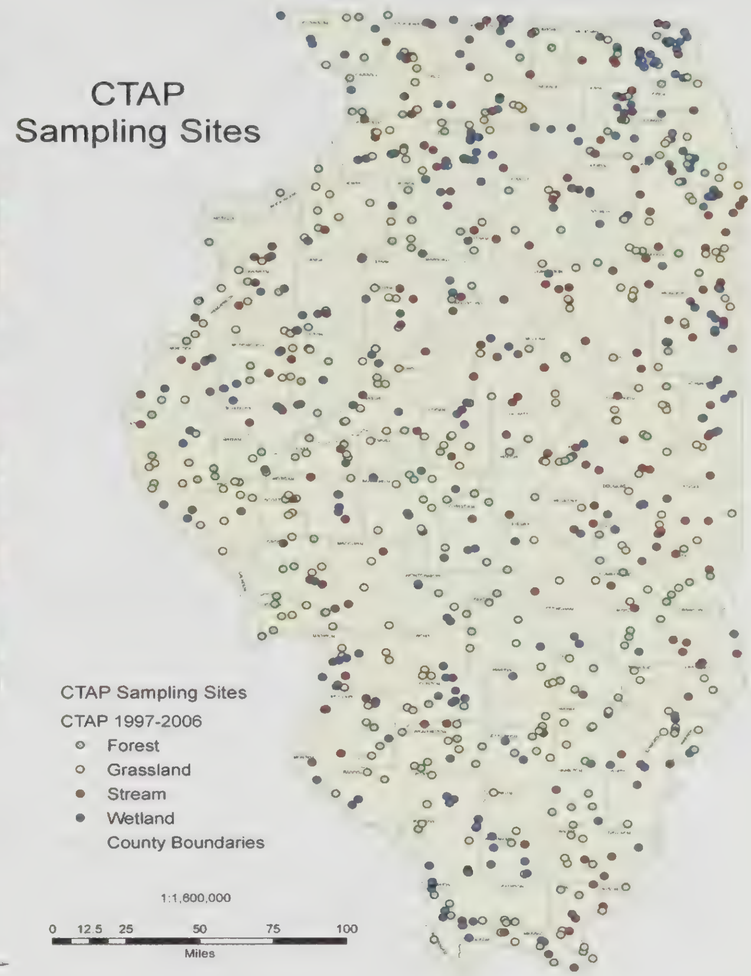

Figure 3.7. Sample locations for the Critical Trends Assessment Program (CTAP) at 600 randomly determined sites throughout Illinois.

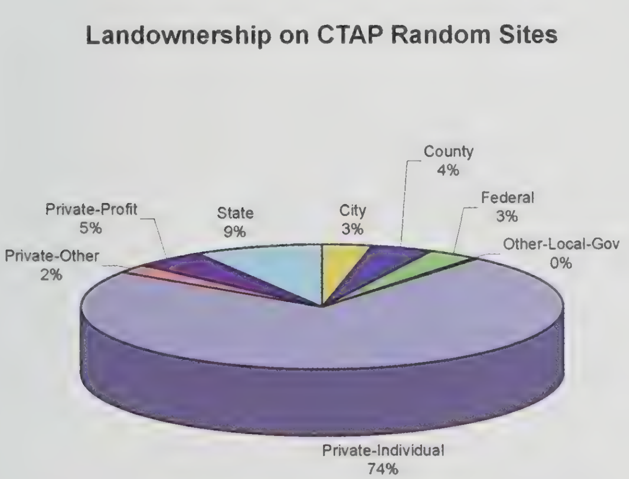

Figure 3.8. Percent landownership at CTAP statewide randomly selected sample sites.

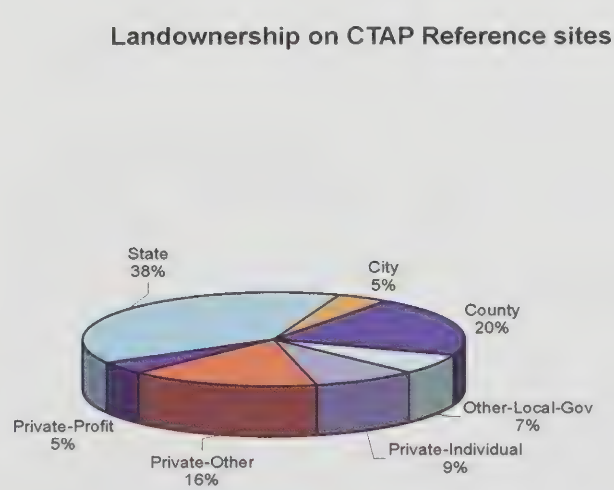

Figure 3.9. Percent landownership at CTAP high-quality reference sample sites.

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CHAPTER 4

Vegetation Ecology and Change in Terrestrial Ecosystems

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OBJECTIVES

What are the major vegetation types that have occurred in Illinois and how have they changed since the last ice age and more specifically since European-Americans settled the region? Ecological factors influencing trends, composition, and diversity in prairie, savanna, open woodland, and forest communities are examined. Historical and contemporary changes will be explored with reference to the proportion and characteristics of habitats remaining in a relatively undegraded condition. While Illinois is a focus for this chapter, the processes and factors explaining vegetational variation have relevance to the entire Midwest and in many cases beyond.

INTRODUCTION

Vegetation change is a major focus of ecological monitoring and research and has both temporal and spatial aspects. Of course, all change is measured through time. Change can be evaluated on a time scale of thousands of years, such as following Pleistocene glaciation, or in the time frame of an annual species. An example of a spatial aspect of vegetation change is the emergence of forest where once prairie occurred (see Fig. 3.11). This was a common occurrence in the Midwest following a post-settlement decline in fire frequency. Other examples are the potential effects of climate warming on vegetation such as the projected migration of tree species to more northern locations (1), something that while occurring over an extended time period would have wide-ranging impacts on associate species of plants and animals including humans. Also, the pace of changes in established plant communities can differ depending on habitat conditions. For example, change can be relatively rapid where resources, such as moisture and nutrients, are not limiting but slower on dry, nutrient poor sites. These ecologically stressful habitats can provide key insights to historical vegetation assemblages because of a slower pace of change. Of course, some quite evident changes occurred in a very short period, such as the conversion of prairie to plowed field. Overall, the degree and magnitude of regional vegetation changes since the Pleistocene (about 14,000 years ago) and habitat destruction during the past 200 years have been extensive. Understanding these processes and their consequences is a key step in conserving biodiversity. The following chapter explores the dominant types of native terrestrial vegetation and changes as they have occurred in Illinois primarily since Pleistocene glaciation with a focus on the post-European settlement period.

IN THE FORMER TIME

The last glacial episode, known as Wisconsinan glaciation, covered the northeastern quarter of Illinois from about 30,000 to 14,000 years ago (see Fig. 2.3). Vegetational changes since that time throughout Illinois included a tundra phase followed by a period of domination by spruce and fir and then spruce/pine forests (2, 3, 4). Just how far south these northern species occurred in Illinois is unclear, but there is fossil pollen evidence of spruce woodland and tundra occurring in central Illinois during the late Pleistocene (4) and of tundra extending to Williamson County in southern Illinois (2). This boreal phase lasted a few thousand years, but by 9,000 years before present (B.P.) deciduous forest began to invade with the development of a warming cycle known as the hypsithermal interval (5, 6). By about 8,300 years B.P., forests were dominated by oak and hickory (7) and prairie species began to invade (4) forming a Prairie Peninsula (8) extending east to Ohio (Fig. 4.1). Although there is regional variation, the period from about 8,000 years B.P. to 5,000 years B.P. included the emergence of savannalike habitats (9, 10). Increased moisture in the southern portion of the Prairie Peninsula about 5,000 years B.P. resulted in an increase in forest (4). Fire, periodic droughts, and grazing animals helped maintain grassland

during this period (11, 12). While oak and hickory species were dominant in upland forests, bottomland forests included species such as Silver Maple (*Acer saccharinum*), Cottonwood (*Populus deltoides*), Green Ash (*Fraxinus pennsylvanica* var. *subintegerrima*), Hackberry (*Celtis occidentalis*), Sycamore (*Platanus occidentalis*), as well as bottomland species of oak and hickory (e.g.,. Bur Oak [*Quercus macrocarpa*], Swamp White Oak [*Q. bicolor*], Pin Oak [*Q. palustris*], Overcup Oak [*Q. lyrata*], Kingnut Hickory [*Carya laciniosa*], Pecan [*C. illinoensis*], and Bitternut Hickory [*C. cordiformis*]).

Vegetation history in North America can be divided conveniently into two periods: pre- and post-European colonization. In Illinois, this division between the two periods occurred from about 1800 to 1840. At that time, results from Government Land Office surveys indicate that about 97% of the state was prairie and forest (19,713,123 acres of prairie [54.7%] and 15,301,598 acres of forest and savanna [42.3%]); the remaining lands were in other, mostly wetland, cover types (Chapter 3). There are trees still standing that were mature at the time of this change in cultural domination. Bur Oak, for example, can live to about 340 years and White Oak to over 400 years. Senior trees bearing an open-grown crown structure, still found scattered throughout the state, stand as testimony to the open prairie and savanna conditions from where they grew. In places, this aspect remains but usually under highly modified circumstances (Fig. 4.2).

This distinction in time may seem arbitrary given that humans and human cultures were well-established throughout the western hemisphere prior to contact with European colonists (13). However, attitudes about land use were very different between native cultures and the colonizers and these differences influenced vegetation and wildlife in many complex ways. The impacts of these cultural influences are a matter of scale. Both cultures had agriculture and utilized natural resources. However, the Europeans came from a landscape that long ago largely had been tamed. The key differences are that prior to European colonization, human disturbances in North America involved local perturbations and regional effects (e.g., broadcast-scale fire) forming a dynamic mosaic within a wilderness context (14). Post-settlement changes can be characterized as an inverse image of the pre-settlement landscape with small, local remnants of native vegetation surrounded by a predominant landscape significantly altered by anthropogenic land-use practices. The following sections detail these changes in prairie, savanna/open woodland, and forest communities, using as a template remnants of native vegetation, our canaries in the contemporary environment.

Figure 4.1. The Prairie Peninsula of Transeau (8) showing the three prairie types found in the central plains and midwestern states and provinces in North America. Modified from Robertson (161).

Figure 4.2. Degraded "savanna" with Bur Oaks and Eurasian meadow understory, Livingston County, Illinois. Photo by J. Taft.

PRAIRIE

PART I — DISTRIBUTION AND GENERAL ECOLOGY OF THE CENTRAL PLAINS GRASSLANDS

The grasslands of central North America originated in the Miocene-Pliocene transition, about 7–5 million years B.P., when a drying period began. The Miocene uplift of the Rocky Mountains created a partial barrier between moist Pacific air masses and the interior portion of the continent. Also, the spread of the Arctic ice sheet, by tying up atmospheric moisture, contributed to increased aridity. Woody plants are generally less well adapted to drought than most grass species and the spread of the grasslands occurred at the expense of forests. As the grassland expanded, there was an increase in the number of grazing and browsing

animals, indicating that the association of grasses and grazers has occurred over a long period of time (15, 16).

The prairies of Illinois were part of the Prairie Peninsula (8), as previously noted a large triangular wedge of grassland that extended from the foothills of the Rocky Mountains eastward into the Midwest with scattered outliers in southern Michigan, Ohio, and Kentucky (Fig. 4.1). Because the Rocky Mountains intercept moist air masses moving eastward from the Pacific Coast, the grassland lies in the partial rain shadow to the east. From west to east within the central grasslands, annual precipitation increases from 25–38 cm to 75–100 cm and becomes more reliable, potential evapotranspiration decreases, the number of days with rainfall increases, and periods of low humidity and periodic droughts in July and August decrease (17).

Ecologists traditionally have separated the central grassland into three major divisions (Fig. 4.1). The arid western shortgrass prairie is dominated by species such as Buffalo Grass (*Buchloe dactyloides*), Blue Grama Grass (*Bouteloua gracilis*) and Hairy Grama Grass (*B. hirsuta*) that reach only 30–45 cm in height. The mid- or mixed-grass prairie occupies the middle sector of the central grassland and is dominated by grasses that are 50–120 cm tall, including Little Bluestem (*Schizachyrium scoparium*), Needlegrasses (*Stipa spartea* and *S. comata*), and native rye/wheat grasses (e.g., *Elytrigia smithii* and *E. dasystachya*). The prairies of Illinois are in the eastern portion of the central grassland, the tallgrass prairie. While the region is subject to periodically severe droughts, typically this area receives supplemental moisture from the Gulf of Mexico, contributing to relatively high annual rainfall compared to the Great Plains grasslands. The dominant grasses on mesic sites include Big Bluestem (*Andropogon gerardi*), Indian Grass (*Sorghastrum nutans*), Little Bluestem, and Northern Dropseed (*Sporobolus heterolepis*), and the first two species can achieve heights greater than 2 m. Wet and wet-mesic prairies are found on poorly drained sites and dominant species include Cordgrass (*Spartina pectinata*) and Bluejoint Grass (*Calamagrostis canadensis*), while on dry sites Little Bluestem and Sideoats Grama (*Bouteloua curtipendula*) are important grasses (17, 18, 19). Prairies in very dry habitats in Illinois (e.g., with substrates of sand or gravel and/or steep exposures) include some of the species from the mixed-grass prairies of the Great Plains.

Because of increased rainfall and reduced evapotranspiration, the climate is increasingly favorable for tree growth from west to east in the central grasslands. In Illinois and the rest of the Prairie Peninsula, the average climate for approximately the past 5,000 years largely appears to have been more favorable for forest than grassland. However, to understand factors influencing the persistence of grasslands in this region it is necessary to consider climatic extremes rather than averages. Periodic droughts have occurred when forests retreated and grasslands advanced or were maintained. Furthermore, droughts most detrimental to woody species are those that result in inadequate winter recharge of deep soil moisture. Nevertheless, despite such periodic climatic extremes, other factors are needed to account for the persistence and predominance of prairie in the Midwest. Prairies in this region probably would have converted to forest during the past 5,000 years if it had not been for occasional prairie fires set by lightning and the nearly annual burning by North American native peoples (15, 20, 21). The role of Indians in maintaining the prairies and the reasons they burned these grasslands has been discussed and documented by various authors (e.g., 20, 22, 23, 24).

Although many woody species such as oaks (*Quercus* spp.) readily resprout after being top-killed by fire, prairie species generally are better adapted to burning than are most woody plants. The adaptation protecting grasses and forbs from fire is their annual growth habit that dies back to underground organs each year, exposing only dead material aboveground (25). Prairie fires become very hot above ground and on the surface of the soil (26, 27) but because fires move quickly and soil is a good insulator, there is little penetration of heat into soil (164). Consequently, growth zones below the soil surface are protected from the heat. The same adaptation protecting prairie plants from fire also protects them from desiccation during drought and periodic grazing (25, 28, 29).

Grasslands can produce more biomass annually than can be decomposed in a year; however, total grassland productivity can decline if this excess plant litter is not removed by fire or grazing (30, 31). Because productivity of prairie gradually can decline in the years following burning, in the absence of large mammal grazers, an approximate balance between biomass production and decomposition in Illinois prairies on mesic sites is reached in about two or three years after burning (32, 33). Grasslands evolved under conditions of periodic drought, fire, and grazing and are adapted to all three (29, 34, 35, 36).

Grazers in North American grasslands range in size from minute arthropods (see Chapter 7) to large grazers, such as Bison. Bison are considered to be a keystone species in some grasslands (37) and historically were the most important large mammalian herbivore in prairies. The extent of the role of Bison in presettlement Illinois is a subject of some debate as there is little evidence for the occurrence of Bison in Illinois prior to 1,000 A.D., although there is substantial evidence for their presence after that time. At the present time, with the elimination of Bison from Illinois prairies, the large herbivore having the greatest impact on tallgrass prairies is the White-tailed Deer. This herbivore may be having a negative impact on prairie diversity, composition, and structure under some conditions (see sidebar on Deer Browse).

In addition to biotic and abiotic interactions of prairie species with fire, climate, and grazers, most prairie plants form endomycorrhizal (myco = fungus and rhizo = root) associations with specialized fungi (42, 43). Exceptions include species occurring on very wet or highly disturbed sites. Endomycorrhizal fungi colonize the root system of the plant and produce threadlike hyphae that grow between and within (thus Endo) cortical cells in the outer part of the plant root. Fungal hyphae also extend outside of the root and act as a supplemental root system provisioning the plant with water and inorganic nutrients.

DEER BROWSE— While the Bison diet is about 90–95% grass, and they consume almost no forbs, White-tailed Deer selectively browse forbs and utilize little amounts of prairie grasses from May through August. Under conditions of high deer density (32–50 deer per km^2) at Goose Lake Prairie State Park in northeastern Illinois, diversity of the forbs declined. The decline in diversity occurred because evenness (a measure of equitable distribution of species) decreased, as species preferred by deer, such as Ashy Sunflower (*Helianthus mollis*), Culver's Root (*Veronicastrum virginicum*), and Sweet Black-Eyed Susan (*Rudbeckia subtomentosa*) decreased in abundance, whereas the abundance of unpreferred species including Old Field Goldenrod (*Solidago canadensis*), and species tolerant of browsing such as Rosinweed (*Silphium integrifolium*), increased in abundance (38, 39). However, in areas that received complete protection from browsing, diversity also declined. Under these conditions species that were sensitive to deer browsing increased in abundance, and species that had increased under conditions of high deer density declined in abundance, presumably, because they were out-competed by the browse-sensitive species. No species were eliminated by deer browsing so species richness was the same under conditions of low and high deer browsing pressure, although loss of species can occur if browsing intensity is high for an extended period of time. These results indicate that forb diversity will be maximized with intermediate levels of deer browsing (39). Thus, deer browsing can negatively or positively affect forb diversity depending upon the deer density and browsing intensity. Nevertheless, the quality of the forb community (sensu 40) will decline with deer browsing, because the browsing sensitive species tend to be more conservative species (typical of higher quality remnants) than browse-tolerant species (41).

especially relatively immobile nutrients such as phosphorus. The specialized fungi cannot grow without association to the plant root and are solely dependent upon plant photosynthesis for their energy source. This relationship can be mutualistic but under conditions of high availability of phosphorus it may be more parasitic or commensalistic (44), the latter term describing an apparent association where one species benefits from but does no particular harm or favor to another organism. Under conditions of high phosphorus availability the plant invests energy in the association but it does not gain the benefit of receiving increased amounts of a limiting soil nutrient. Under these conditions the fungus benefits from the association but the plant does not (45). Plants with fine fibrous root systems like cool-season (C3) grasses have less dependency on the mycorrhizal association than prairie forbs and coarse-rooted warm-season (C4) grasses such as Big Bluestem and Indian Grass (46, 47). Cool-season plants with the C3 photosynthetic pathway achieve most efficient growth during cool, moist conditions while plants with the C4 photosynthetic pathway achieve most efficient growth during warm, dry conditions. Nevertheless, plants may benefit from the mycorrhizal association even if they do not gain increased availability of inorganic nutrients, because the association can protect some plants from soil pathogens (48) or mitigate the effects of grazing (49).

PART II—PRAIRIE TRENDS IN THE PRAIRIE STATE

Prairies at the time of European settlement (circa 1820)

While it has been calculated that prairie comprised about 55% of the presettlement Illinois land cover (see Fig. 3.7), this is a point-in-time reference and the vegetation was primarily a shifting mosaic of prairie, savanna, and forest that was largely controlled by fire frequency under climatic conditions capable of supporting any of these vegetation types. Fire frequency largely was determined by topography and the occurrence of firebreaks such as waterways and dissected landscapes (50). Across landscapes that are level to gently rolling, fires carry readily, but in hilly and dissected landscapes the spread of fire across the landscape is more limited (51). Fires tend to carry well uphill, because rising convection currents encourage fire movement; but spread of fire down slopes tends to be slowed by the rising convection currents. The importance of waterways in determining the distributional patterns of forest and prairie in presettlement Illinois was demonstrated by the noted early ecologist/botanist Henry Allen Gleason through the use of the Government Land Office records for some Illinois counties (52). Gleason observed that prairies were more associated with the western sides of streams while forests, although often found on both sides of a stream, generally were more developed on leeward eastern sides. This pattern was attributed to the prevailing westerly winds that carried fires from west to east, so that west sides of waterways burned more frequently than east sides. While forests generally can be described as having affiliation with water courses (e.g., Fig. 3.7), prairies also occurred in the floodplains of the major rivers (53, 54, 55). Some areas of the Grand Prairie Natural Division were seasonally flooded. While fire would have been a factor during dry periods, saturated soils is another factor that limited woody encroachment in poorly drained regions.

PRAIRIE TRENDS SINCE EUROPEAN SETTLEMENT

The presettlement prairies of Illinois were drastically altered by the influx of Euro-American settlers. The earliest settlers entered the unglaciated southern portion of the state. This was a familiar landscape since these people mostly were hunters and trappers from forested regions of Tennessee, Kentucky, and West Virginia. As they migrated northward, they followed the finger-like traces of forest along the major waterways, and initially avoided the larger tracts of prairie. The larger tracts of prairie were avoided in favor of smaller tracts that were adjacent to waterways and timber for a variety of reasons. The settlers needed water for their livestock and to turn water wheels for a source of power. Timber was needed as a source of fuel and for building materials and the large tracts of prairie exposed the settlers to the force of the winter storms (11). Timber was considered to be such an important commodity on the prairie that counties were not allowed to form as governmental units until it could be demonstrated that they had access to an adequate amount of timber to support development (56).

It is of interest that cool-season grasses, such as the exotic Kentucky bluegrass (*Poa pratensis*) were favored by the European settlers as forage for their livestock over the native grass species. Bluegrass provided green forage a month earlier in the spring and a month later in the fall than the native species (56). Because the native grasses evolved under a system of intermittent grazing pressure, they could

be eliminated by exposing them to continuous grazing. Within a couple of years of continuous grazing the native species would decline and Kentucky Bluegrass would invade and become dominant.

Many of the earliest settlers believed that prairie soils were infertile. They had been familiar with life in the forest and thought that soils that appeared incapable of supporting trees surely would not be productive for crops. However, rather than being infertile, a characteristic of these grasslands is that about two-thirds of the plant biomass is located beneath the surface of the soil in the form of roots and other underground organs. As belowground and aboveground portions die and decay, they greatly enrich the soil with organic matter. But turning over the thick prairie sod was an almost insurmountable obstacle to early prairie farmers until 1837 when John Deere, in Grand Detour, Illinois, invented the self-scouring moldboard steel plow. As counties were settled, one of the first industries to develop was clay tile manufacturing for draining the seasonally wet prairies common throughout much of the Grand Prairie region. The combination of drainage tiles and the moldboard steel plow set the stage for the conversion of prairie to cropland. However, even though settlers learned of the fertility of the prairie soil and could raise large crops, at first many of the larger tracts of prairie remained unsettled because of the lack of a transportation system that could get the crops to distant markets. With the coming of the railroads in the 1850–60s, there was a rapid conversion of the prairies to cropland (11). During this period, about 3.3% of the prairie was plowed each year (57) and by the late 1800s, most of the prairie was gone (58). Documented objections to this dramatic conversion (e.g., 59) apparently were few.

As the prairies were converted to an agricultural landscape, fires that had swept nearly annually across the landscape in presettlement times were actively stopped by the settlers who viewed them as a threat to their economic security. According to Gerhard (60), "The first efforts to convert prairies into forest land were usually made on the part of the prairie adjoining timber..., three furrows were plowed all around the settlement to stop the burning of the prairies..., whereupon the timber quickly grows up...". The settlers also indirectly stopped the fires by increasing plowed fields and roads which acted as firebreaks. Cessation of these nearly annual conflagrations served to further the demise of the prairies, as many of them were converted to savanna and then forest by invading tree species that were no longer restricted by the periodic fires.

What remains in the contemporary landscape is an archipelago of small and isolated prairie patches lacking the full complement of natural processes such as grazing by large herbivores (e.g,. Elk and Bison) and landscape-scale fires that would promote a dynamic mosaic of burned and unburned prairie. Instead, prairies that are treated with prescribed fire are burned relatively infrequently (e.g., every three to five years) compared to background levels (e.g, 61), and the burns probably are less patchy. Typically, about 50% of a site is burned at one time to provide an unburned refuge for fire-sensitive arthropod species dependent on prairie plants. Further, the isolation of remnants limits the migration of species needed to compensate for natural population declines. Monitoring prairies over time is vital to determine whether these last remnants of our natural heritage can be maintained. Research in Wisconsin prairies suggests species losses can be expected over time in small, isolated prairies at rates that can deplete 50% of the flora in about 50 years (62). At risk in particular are species of short-stature, nitrogen-fixing species (e.g., legumes and New Jersey Tea [*Ceanothus americanus*]), and species with small seeds. Observed rates of species losses were greatest on moist sites compared to dry sites (62); however, dry prairies also have lost low-stature forb species that are habitat specialists (63). These observations suggest that with typical modern fire return intervals, a more rapid decline can be expected in wet prairies compared to prairies on more elevated topographic positions. Few wet prairies persist today in part due to fire absence but also due to drainage activities and conversion to agriculture. Biennial burning appears necessary to maintain mesic and wet-mesic prairies and limit encroachment by woody and non-native species (61). Trends in unburned prairies on sandy soils (sand prairies) suggest there have been losses among native species and increases among non-native species while burned prairies have increased in native species richness and had declines in non-native species (64).

TABULATING REMAINING PRAIRIE - THE INAI AND RAILROAD PRAIRIE SURVEYS

Results from the Illinois Natural Areas Inventory (INAI) indicate that only about 2,496 acres (0.013%) of the original prairie remain in a relatively undegraded condition (65; data revised in 2007). Prairie remnants mostly are small and isolated, like islands in an agricultural sea (Fig. 4.3). The majority among size classes are in the 1–5 acre category (44%) and, of the 231 prairie remnants recognized by the INAI, 79% are smaller than 10 acres and 22.5% are less than 1 acre (Fig. 4.4). Had the goal of the pioneers been to eliminate prairie from the Prairie State, a 99.99% success rate surely would have seemed unimaginable.

A particularly dramatic example of prairie habitat loss can be found regionally in Illinois. The Grand Prairie Natural Division (as a concession to reality, recently coined the Central Corn Belt Plains Ecosystem [see Chapter 2]), at nearly 13 million acres, is the largest Natural Division in Illinois. Only about 475 acres (about 0.004% of total area) of relatively undisturbed prairie (Grades A and B) have been identified by the INAI in this region. The 9,531,000-acre Grand Prairie Section of this natural division contained mostly species-rich prairie on silt-loam soils—the "black soil" prairies. However, only 213 acres (about 0.002% of the total in the early 1800s) of relatively undegraded prairie have been identified in this section. Champaign County in east-central Illinois was estimated to have about 592,300 acres of prairie; currently, a single acre qualifies for the INAI and only following extensive restoration at this pioneer cemetery plot (Fig. 4.5)

An important refuge for prairies, particularly in the Grand Prairie Natural Division, is in pioneer cemeteries (Fig. 4.5), a fitting resting place for some of the finest examples of prairie remaining in the heavily agricultural eastern region of the tallgrass prairie ecosystem. Whether these small

remnants of our tallgrass prairie natural heritage can persist in isolation is a subject of ongoing research. These small prairies actually have been found to be smaller than they appear. Marginal areas have higher exotic species numbers, lower native plant diversity, and a more ruderal (weedy) species composition among the native species. Further study will determine if these edge zones are stable, expanding, or contracting over time and whether site-level diversity can be maintained (John Taft, unpublished data).

Ironically, the railroads that brought change and enabled the development of an agricultural economy also provided another important refuge for prairies, the so-called "railroad prairies" located in railroad rights-of-way (RR ROW). Railroads were established before the landscape was extensively disturbed and the rights-of-way, which usually extended for 100 feet on either side of the track, often were fenced to keep out livestock. In addition, the RR ROW formerly were managed with periodic fire (as well as many accidental fires) limiting the invasion of woody species. In the last 30 or more years, many of the remnant prairies along the railroads have disappeared or become degraded as a result of fire absence, herbicide use, and other disturbances (e.g, installation of fiber optic cables, vehicle trespass, and cultivation). Furthermore, many of the railroad lines have been abandoned. Frequently, these abandoned ROW, often the only local remnants of native prairie, have been acquired by the adjacent land owner, plowed, and converted to cropland (Fig. 4.6). Nevertheless, some prairie persists along RR ROWs, although much has been degraded (see sidebar on Railroad- roadside Prairies).

Figure 4.3. Prospect Cemetery Prairie Nature Preserve in Ford County, Illinois. Surrounding lands primarily are agricultural. Photo by J. Taft.

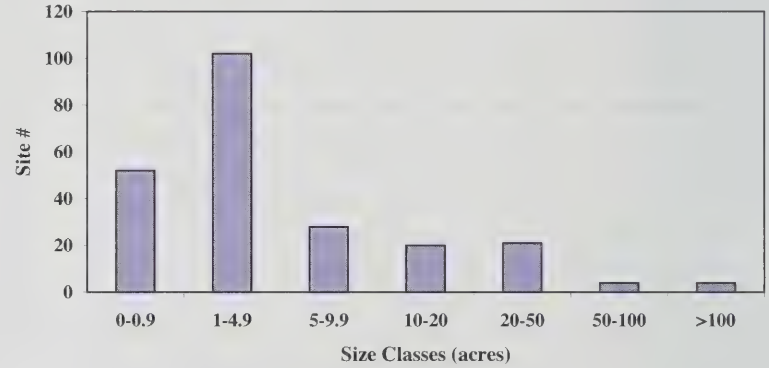


Figure 4.4. Distribution of INAI (Illinois Natural Areas Inventory) grades A and B prairie remnants by size classes.

PART III - COMMUNITY CLASSIFICATION, SPECIES DIVERSITY, AND ONGOING ECOLOGICAL THREATS

Characteristics of Illinois Prairies Today

The numerous prairie community types recognized in Illinois (Chapter 2) reflect the great variety of physiographic conditions found statewide that influence species composition including variation in topography, slope aspect, drainage, bedrock geology, and soil characteristics. Prairie types (Subclasses in the INAI classification) include *Prairie* ("black-soil" prairie on silt-loam soils), Sand Prairie, Hill Prairie, Gravel Prairie, Dolomite Prairie, and Shrub Prairie (67). Other than Hill Prairies and Shrub Prairies, these categories are further classified into community types by distinguishing variation along the moisture gradient (e.g., dry, dry-mesic, mesic, wet-mesic, wet). While total acreage is low, high-quality examples remain of each community type. Prairies on silt-loam soils originally were by far the dominant type; today they account for only about 25% of high-quality remnant acreage. A disproportionate amount of prairie meeting the qualitative criteria for the INAI occur on the more agriculturally unsuitable lands (Fig. 4.8), such as Sand Prairies (49%) and Hill Prairies (18%). The following descriptions are based on typical examples. However, substantial variation exists in species composition as influenced by the moisture gradient and regionally in Illinois.

Figure 4.5. Tomlinson Cemetery Nature Preserve, the last remaining acre of high-quality prairie in Champaign County, Illinois. Pioneer cemetery prairies are among the last refuges for tallgrass prairie in the Grand Prairie Natural Division.
Photo by J. Taft.

Prairie — Within Illinois, tallgrass prairie on silt-loam soils, the "black-soil" prairie, was the dominant prairie type. About 636 acres among 88 sites, averaging 7.2 acres, remain in undegraded condition (Figs. 4.8, 4.9). Among community types, wet and wet-mesic prairies were quite common, especially in the Grand Prairie region (see Figure

Figure 4.6. Marlin Bowles of the Morton Arboretum points to a population of the federally threatened Mead's Milkweed (*Asclepias meadii*), see inset, discovered in Grade A prairie in a railroad right-of-way (Vermilion County). This population and prairie both were destroyed to increase cropland once the rail line was abandoned and the land was transferred to the adjacent land owner. Photo by J. Taft.

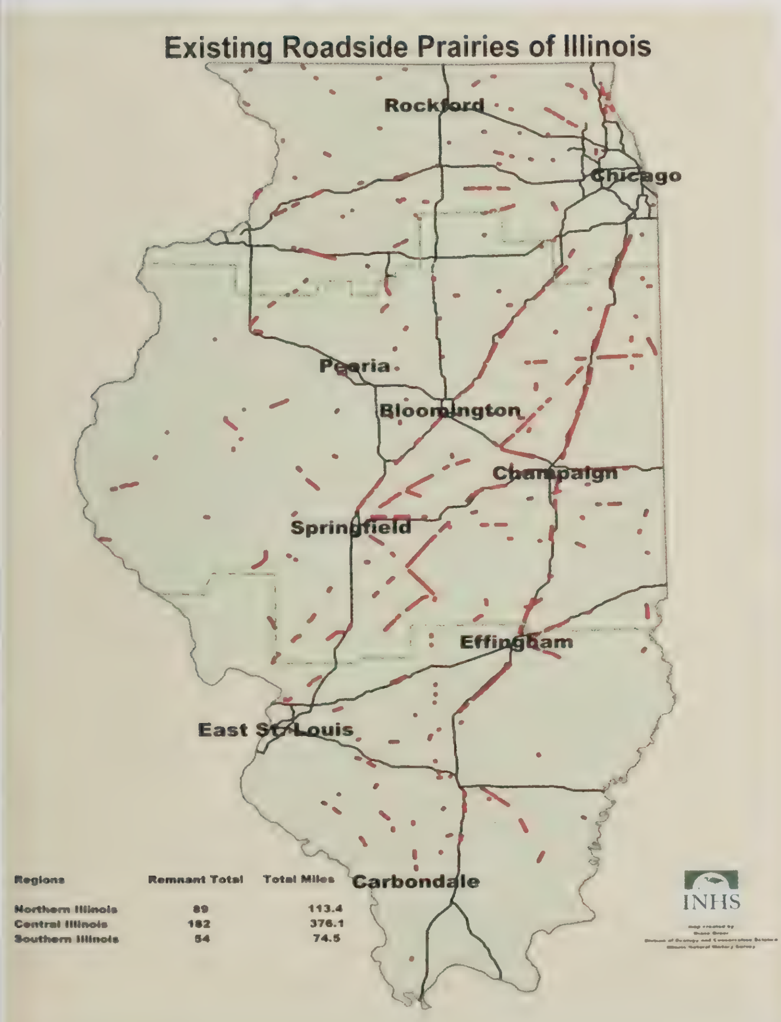


Figure 4.7. Location of prairies identified in a survey of railway and roadside ROWs by William C. Handel (INHS).

Railroad-roadside Prairies by W.C. Handel

To document the current status of prairie in shared roadway-railroad rights-of-way (ROW), an inventory was conducted of remaining prairies throughout Illinois from 2001 to 2003. In previous work, the Illinois Natural Areas Inventory (65) surveyed the state for ROW prairies, identifying only those areas that met criteria for relatively undisturbed, high-quality prairie (66). However, no comprehensive survey for remnant prairies in shared ROW had been conducted. Such areas have provided local refugia for native prairie species; however, typical vegetation management in these ROW involve mowing and herbicide applications, severely threatening the continued existence of these remnants. A main goal of the survey was to identify all remaining prairie habitat in these shared ROW to reduce or eliminate these damaging management practices where prairie was present. To assist with the field survey, maps were prepared using Geographic Information System (GIS) data layers of all areas where there were shared ROW within 200 feet of a rail line. This mapping effort indicated that there were 3,511 miles of shared ROW in Illinois that potentially could have prairie (or savanna) vegetation. The survey was conducted during the growing season months of April to October by region in the state (Fig. 4.7).

A qualitative rating class was assigned to prairie remnants (1 [highest], 2 [intermediate], or 3 [poor]). Some remnants included two or more quality classes. The type of prairie communities were recorded along with information on the physical dimensions of each remnant, evidence of past management, and perceived threats including presence of non-native species, woody invasion, or anthropogenic disturbances such as mowing, cultivation, or herbicide spraying. Finally, a species list was generated for each remnant. All ROW prairies were inventoried even if they were of extreme low quality. All remnant prairies can be important for the overall preservation of the remaining prairie ecosystem. For example, even degraded remnants provide cover, habitat, and dispersal corridors for grassland flora and fauna, including game species such as Northern Bobwhite (*Colinus virginianus*) and the non-native Ring-necked Pheasant (*Phasianus colchicus*). Also, these linear corridors typically cross many different soil types and soil moisture zones providing a wide range of habitat conditions capable of supporting a diverse mixture of species. Consequently, ROW prairies also provide a valuable source of seed of local ecotypes that can be used in prairie restoration and reconstruction efforts.

The survey found 325 prairie and savanna remnants totaling 564 miles (16% of all shared ROW) totaling about 4,500 acres. The most common type of prairie community found was dry-mesic prairie (72%). Most of the remnants were low quality, Class 3 prairies (65%). Only 13%, 41 out of 325, were considered Class 1. Non-native vegetation occurred in 95% of sites and was the most common threat to native prairie and savanna remnants (Table 4.1) followed by mowing at 41% of sites. Although it is apparent that the roadside prairie and savanna communities are at risk, there are some positive signs. Many of these remnants have the potential for large-scale restoration with proper management. Information gathered from this survey is now incorporated into a GIS database that is being utilized by the Illinois Department of Transportation and the Illinois Department of Natural Resources to facilitate conservation and preservation of the remaining rialroad-roadside prairie and savanna habitat in the state.

2.6), but due to drainage and conversion to agriculture in this region, very little remains. About 294 acres remain in the state, mostly in northeastern Illinois (urban expansion has been slightly more forgiving to prairie than rowcrop agriculture in the corn/soybean belt). Mesic prairie was probably the most common prairie community type throughout Illinois; however, a scant 279 acres remain in a high-quality condition. Details of the composition of mesic black soil prairies are available primarily from these persisting remnants, which as noted tend to be small, isolated fragments, termed "nanoprairies" (68). Nevertheless, these remnants often are very diverse at the local scale (termed point or alpha diversity), averaging 12 to 15 species in 50 cm x 50 cm sampling quadrats, and up to about 160 species in small (e.g., 4-acre) remnants.

Dominant species in mesic prairies include the typical prairie grasses such as Big Bluestem, Indian Grass, Little Bluestem, and Northern Prairie Dropseed as well as several sedges (*Carex* spp.). However, perennial forbs tend to be most abundant in terms of species richness and total percent cover while other species groups such as sedges, nitrogen-fixing species, annual forbs, and hemi-parasites (root parasites that also photosynthesize) also are represented (Fig. 4.10). Dominant forbs include Common Spurge (*Euphorbia corollata*), Pasture Rose (*Rosa carolina*), Heath Aster (*Aster ericoides*), and Wild Strawberry (*Fragaria virginiana*) (19). Other common forbs include Rigid Sunflower (*Helianthus rigidus*), Prairie Phlox (*Phlox pilosa*), Rattlesnake Master (*Eryngium yuccifolium*), Grey-Headed Coneflower (*Ratibida pinnata*), and Rosinweed. The vast majority of diversity, as in most plant communities, is among the numerous species with intermediate or low levels of frequency (i.e., species that have sparse occurrences both within and among sites).

In a monitoring study of three east-central Illinois pioneer cemetery prairies, all on silt-loam soils and between three and four acres in size, 206 species have been recorded of which 160 (78%) are native. Without intervention and control efforts by volunteers and site managers, continued increases among some of the non-native species would threaten the integrity of the sites, all dedicated nature preserves. Some of these problem exotics are:

Kentucky Bluegrass (*Poa pratensis*)
Daylily (*Hemerocallis flava*)
Wild Parsnip (*Parnassia sativa*)
White Sweet Clover (*Melilotus alba*)
Yellow Sweet Clover (*Melilotus officinalis*)
Cut-Leaved Teasel (*Dipsacus laciniatus*)
Smooth Brome (*Bromus inermis*)
Lily-of-the-Valley (*Convallaria majalis*)

In these sites, Kentucky Bluegrass, a species from Eurasia rather than Kentucky, is the most abundant species overall occurring in over 90% of vegetation sample quadrats. Despite these problems, these pioneer cemetery prairies retain a rich diversity of native prairie species and are important relicts of the natural history of the Prairie State (Fig. 4.11).

Sand Prairie—This subclass of prairie occurs primarily in the northern half of Illinois and is located on deep sands deposited by glacial melt waters following the Woodfordian substage of the Wisconsinan glacial advance and on sandy glacial lakeshore deposits (69). The coarse textured sandy soils often were transported locally by wind (termed aeolian sands) after initial deposition forming localized small dunes. Such soils have very limited capacity to store available moisture (or nutrients) for plants; consequently, plant species adapted to drought conditions often are favored (70, 71). Sand prairies include specialized habitats such as sand blow-outs, relatively bare patches created by wind action, with a specialized flora (Fig. 4.12). Where the water table seasonally intersects with sandy deposits, habitat for wet to wet-mesic sand prairies also occurs. Mesic sand prairies occur in intermediate zones between wet and dry soils on relatively richer sandy loam soils.

A total of 37 high-quality remnants of sand prairie are known at this time in Illinois totaling 1,217 acres (modified from 65 using unpublished data from the IDNR Natural Heritage Database). Dry and dry-mesic sand prairies are the most common types with about 776 acres remaining in a high-quality condition compared to 441 acres for mesic, wet-mesic, and wet sand prairies combined (Fig. 4.8). These drier prairies are somewhat more resistant to disturbance than silt-loam tallgrass prairie. Many agricultural weeds are adapted to more mesic conditions of silt-loam soils but are ineffective competitors in dry sand prairies. As efforts to cultivate some fields were abandoned, at some sites portions of the native prairie flora even became reestablished. However, with the expanded use of fertilizers and irrigation, sustained agriculture on these soils became possible and more widespread. Mesic sand prairies have similarity to mesic silt-loam prairies including many of the same invasive species problems. Once weeds become established in mesic sites, they can limit recolonization by prairie species (20).

In dry to dry-mesic sand prairies, dominant species (based on 72) include:

Little Bluestem
Western Ragweed (*Ambrosia psilostachya*)
Beach Three-Awn Grass (*Aristida tuberculosa*)
Panic Grass (*Dichanthelium villosissimum*)
Sand Love Grass (*Eragrostis trichodes*)
Prickly Pear Cactus (*Opuntia humifusa* and *O. macrophylla*)
Goat's Rue (*Tephrosia virginica*)
Golden Aster (*Heterotheca camporum*)
Slender Sand Sedge (*Cyperus lupulinis*)
Gray's Sedge (*Cyperus grayioides*).

Additional characteristic species specifically associated with the Mississippi River sands include (Ebinger, unpublished data):
June Grass (*Koeleria macrantha*)
Rock Selaginella (*Selaginella rupestris*)
Sand Bracted Sedge (*Carex muhlenbergii*)
Smooth Fruited Oak Sedge (*Carex tonsa*)
Hairy Gramma (*Bouteloua hirsuta*)
Specialists in sand blow outs include Beach Heather

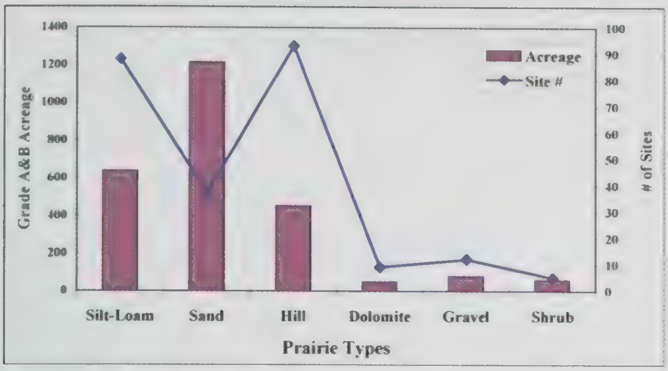


Figure 4.8. Sum acreage and site number among prairie remnants graded A and B by the Illinois Natural Areas Inventory for each prairie subclass.

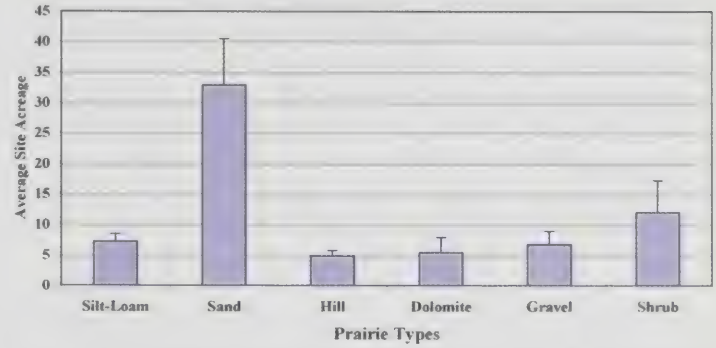


Figure 4.9. Average remnant size for prairies recognized as high quality (graded A or B) by the Illinois Natural Areas Inventory for each prairie subclass. Error bars are standard error.

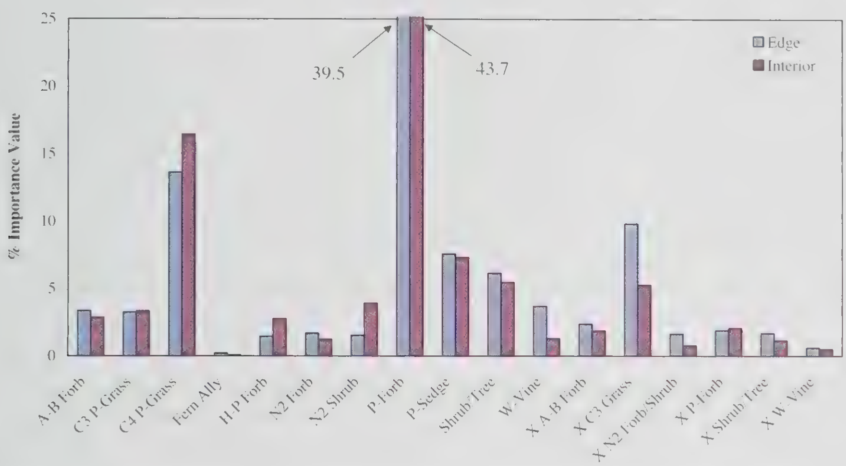


Figure 4.10. Physiognomic group characteristics for edge and interior zones in three high-quality pioneer cemetery prairies, all mesic tallgrass prairies dedicated as Illinois Nature Preserves. X = exotic (non-native), A-B = annual-biennial, P = perennial, H = herbaceous, W = woody, N2 = nitrogen fixing species.

Figure 4.11. Rich assemblage of native prairie species in a mesic prairie remnant in a pioneer cemetery in Ford County (Prospect Cemetery Prairie Nature Preserve). Photo by J. Taft.

Table 4.1. Ecological threats recorded from 325 railroad prairie remnants throughout Illinois.

Threats	# Sites	% of total
Exotics	*309	95%
Mowing	134	41%
Woody invasion	97	30%
Development	19	6%
Cultivation	10	3%
Tree plantings	4	1%
Herbicide or Spraying	3	<1%
Dumping	2	<1%
Digging	1	<1%
Erosion	1	<1%
Recreational vehicles	1	<1%

*Dominant exotics (non-native species) found in RR ROW prairies include Smooth Brome (*Bromus inermis*), Meadow Fescue (*Festuca pratensis*), Wild Parsnip (*Pastinaca sativa*), Reed Canary Grass (*Phalaris arundinacea*), sweet clovers (*Melilotus* spp.), Common Reed (*Phragmites australis*), Autumn Olive (*Elaeagnus umbellata*), and Cut-leaved Teasel (*Dipsacus laciniatus*).

(*Hudsonia tomentosa*), Umbrella Sedge (*Cyperus grayioides*), Silvery Bladderpod (*Lesquerella ludoviciana*), and the heroic James Clammy Weed (*Polanisia jamesii*) (Fig. 4.13).

Locally in southern Cook County there are fascinating remnants of the dune and swale topography of former Lake Chicago beaches. Prairies occurring on these sites are unique in the close association of moist-soil species in the swales and dry prairie species on the dunes (40). Organic matter accumulation in the swales create ideal habitats for some specialized species including many rare for Illinois. Because of this juxtaposition of habitat types, these remnants can support high levels of diversity.

Like other prairie remnants, most individual sand prairies (46%) are small and less than five acres; however, there are individual sites that are much larger. Consequently, overall, sand prairies average 33 acres, the largest mean size among prairie types in Illinois (Fig. 4.9). The largest prairie remnant of all in the state (5,848 acres [2,367 ha]), known as Lost Mound (formerly the Savanna Army Depot located at the border of Carroll and Jo Daviess counties in northwestern Illinois), was a focus of early prairie studies (70). Lost Mound today contains mainly degraded sand prairie, a result of nearly a century of intensive cattle grazing, but also provides habitat for many rare species in Illinois (72). With the cattle removed and fire gradually being returned to the site, there is great hope for successful restoration of a large and dynamic prairie mosaic, providing habitat for a great variety of prairie plant and animals species, a unique and promising opportunity in the eastern region of the tallgrass prairie ecosystem.

Hill Prairies—Hill prairies are specialized habitats that occur on knolls and slopes often adjacent to major rivers. Four hill prairie community types are recognized in Illinois based on substrate characteristics: loess, sand, glacial drift, and gravel hill prairies (67). Of all prairie types in Illinois, hill prairies today are most numerous with 93 high-quality remnants totaling 453 acres (Fig. 4.8). These range in size from a fraction of an acre to 51 acres with average size about 4.9 acres, the smallest average size among prairie types (Fig. 4.9). Loess hill prairies (Figure 4.14) are the most common, comprising 60% of sites and 84% of acreage and are found mainly in western Illinois along the Illinois, Sangamon, and Mississippi rivers (73, 74). Glacial drift hill prairies are the next most common, comprising 32% of sites but only 9% of acreage; they occur in east-central Illinois (75, 76) and along the west side of the Illinois River, primarily north of Peoria. Gravel hill prairies are limited to northern Illinois, are somewhat similar to glacial drift hill prairies, and are few in number and acreage. Only one sand hill prairie has been identified.

Interestingly, hill prairies often were described by early settlers traveling on the adjacent rivers as parklike grassy eminences above the bluffs, sometimes with scattered oaks. A quote from William Cullen Bryant from 1832 is typical as he described the view from the adjoining Mississippi River: "steep walls of rock, the tops of which were crowned with a succession of little round eminences covered with coarse grass and thinly scattered trees, having quite a pastoral aspect" (77). Several settlers mention fire as a common feature of this landscape (78). Such a landscape setting mostly is a thing of the past and a reminder of the changes and threats to the persistence of these important relicts of our natural history.

Hill prairies persisting to the present time (e.g., Figs. 4.14 and 4.15) are limited to ecologically stressful sites on steep slopes, south to southwest exposures, and on soils with limited capacity for moisture storage (73). While ecologically stressful environments, hill prairies are not so severe that woody encroachment is controlled during periods of fire absence. Woody species typically invading hill prairies include Rough-Leaved Dogwood *(Cornus drummondii*), Smooth Sumac *(Rhus glabra*), oaks, and even Sugar Maple (79). Rough-Leaved Dogwood may be a keystone invader as it is clonal, produces abundant fruits that are dispersed by birds, and by shading herbaceous prairie species it reduces fire effects (80). Infestations of this species may produce a cascading effect by modifying the local prairie environment and permitting other woody species to invade. Based on comparisons of aerial photography during a 37-year period, hill prairies along the Mississippi River in Jersey County declined in area about 62% (81). Hill prairies throughout Illinois continue to decline in area due to woody encroachment and many have disappeared altogether. In a study of nine hill prairies using aerial photography to compare changes in area from 1940 to 1990, decline in total area exceeded 50% for all sites, including some managed with prescribed fire and brush removal (82, 83). The decline of these hill prairies follows a predictable pattern. First woody encroachment from surrounding forest fills ecotonal border zones including ravines, increasing the ratio of prairie edge to prairie interior, and eventually dividing the prairie into smaller, more numerous fragments; the smallest eventually becoming imperceptible in aerial photography. Burning these sites at intermediate rates (e.g., every three to five years) does not appear adequate to maintain them and these prairies are at risk statewide (84). Another source of widespread habitat degradation in hill prairies has been livestock grazing (85).

These dry prairies typically are dominated by species such as Little Bluestem and Side Oats Gramma. Additional dominant species (based largely on 19, 73) include:

Indian Grass
Purple Prairie Clover (*Dalea purpurea*),
Common Spurge
Old Field Goldenrod
Scurfy Pea (*Psoralea tenuiflora*)
Sky Blue Aster (*Aster azureus*)
Leadplant (*Amorpha canescens*)
Yellow Flax (*Linum sulcatum*)
Fringed Puccoon (*Lithospermum incisum*)
Smooth Sumac
Scribner's Panic Grass (*Dichanthelium oligosanthes* var. *scribnerianum*)
Pale Beardtongue (*Penstemon pallidus*)

Figure 4.12. A blow out in a sand prairie in Mason County, Illinois. Photo by J. Taft.

Figure 4.13. Specialized species of sand blow outs including: A) Beach Heather (*Hudsonia tomentosa*), B) Umbrella Sedge (*Cyperus grayioides*), C) Silvery Bladderpod (*Lesquerella ludoviciana*), and D) James Clammyweed (*Polanisia jamesii*). *Cyperus grayioides* is Threatened and the rest are Endangered species in Illinois.

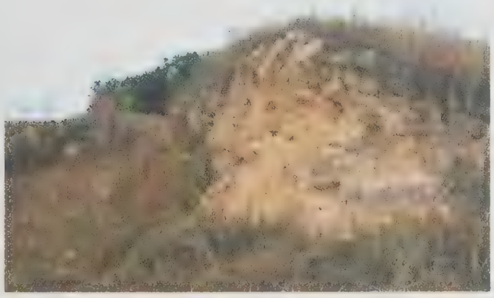


Figure 4.14. Exposure of loess cap at Revis Hill Prairie Nature Preserve, a loess hill prairie in Mason County, Illinois.

Figure 4.15. Fults Hill Prairie Nature Preserve in Monroe County, Illinois showing margin of limestone glade with specialized species including the Missouri Orange Coneflower (*Rudbeckia missouriensis*), a state-endangered species in Illinois.

Wild Petunia (*Ruellia humilis*)
Daisy Fleabane (*Erigeron strigosus*)
Tall Boneset (*Eupatorium altissimum*)
False Boneset (*Brickellia eupatorioides*)

Many species from further west reach their eastern range extent in hill prairies along the Mississippi River, including several listed as threatened or endangered in Illinois:

Spurge (*Euphorbia spathulata*)
Slender Heliotrope (*Heliotropium tenellum*)
Whitlow Grass (*Draba cuneifolia*)
Dwarf Bedstraw (*Galium virgatum*)
Narrow-leaved Milkweed (*Asclepias stenophylla*)

While smaller hill prairies have fewer species than larger remnants and species losses can be expected to have occurred as sites contract in area due to woody invasion (62), small hill prairies still include many conservative species and more than would be predicted based on area alone (84). Similar results have been found with small remnants of silt-loam prairies (86). These patterns suggest that immediate and vigilant efforts to manage remnant hill prairies have the potential to preserve much of their species diversity. Whether these species persist will depend on the level of priority placed on conserving the remaining hill prairies in Illinois.

Dolomite Prairie—Dolomite prairies occur where dolomite is close enough to the surface (e.g., within six feet) to influence species composition (67), primarily along the Des Plaines and Kankakee rivers in Will County. They comprise only about 2% of prairies remaining in Illinois. Moisture classes are dependent on drainage characteristics and depth to bedrock and include dry to wet community types. Many have been degraded by flagstone quarrying and other disturbances including livestock grazing. Formerly, cattle drives to the Chicago stock yards followed the Des Plaines River corridor impacting severely many of the prairies along the way. Nine high-quality remnants are known totaling 49 acres, yielding an average remnant size of 5.4 acres (Fig. 4.9).

Characteristic species depend on moisture conditions. Soils are shallow in dry dolomite prairie and dolomite can be locally exposed. Dominant species are similar to loess hill prairie (e.g., Little Bluestem, Side Oats Gramma). Northern Prairie Dropseed becomes characteristic in mesic dolomite prairies and some species affiliated with calcareous wetlands such as seeps and fens can be found in wet-mesic and wet dolomite prairie including Ohio Goldenrod (*Solidago ohiensis*), Riddell's Goldenrod (*S. riddellii*), Indian Plantain (*Cacalia tuberosa*), and Tufted Hair Grass (*Deschampsia caespitosa*). Several rare species are associated with dolomite prairie (Fig.4.16) including the federally endangered Leafy Prairie Clover (*Dalea foliosa*), False Mallow (*Malvastrum hispidum*), a quillwort (*Isoetes butleri*), and Slender Sandwort (*Minuartia patula*).

Gravel Prairie—Gravel prairies occur on kames or eskers (gravelly mounds deposited by glaciers) and locally on gravel terraces along streams in northern Illinois. Gravel tends to be of a calcareous nature providing a basic pH reaction to these typically well-drained soils (67). Most have been destroyed by gravel mining. Twelve remnants are known totaling 80.8 acres. Average remnant size is 6.7 acres (Fig. 4.9) and gravel prairies comprise about 3.2% of all remaining prairies in Illinois. Typical species include many also found in dolomite prairies (dry to mesic types) together with Pasque Flower (*Pulsatilla patens*), Prairie Smoke (*Geum triflorum*), Low Calamint (*Calamintha arkansana*), Fringed Puccoon, and Rock Sandwort (*Minuartia stricta*).

Shrub Prairie—This community type occurs on acidic sandy soils of the Chicago Lake Plain and Kankakee Sand Area. Only five high-quality remnants are known totaling 60 acres (Fig. 4.8). Characteristics shrub species include Early Low Blueberry (*Vaccinium angustifolium*), Black Huckleberry (*Gaylussacia baccata*), Hardhack (*Spiraea tomentosa*), Black Chokecherry (*Aronia melanocarpa*), and Purple Chokecherry (*A. prunifolia*). Mosses form a nearly continuous ground layer (67). Hazel thickets (*Corylus americana*) also were a feature of some prairie border areas (87), but few extensive examples remain.

How Many Prairie Species Are There?

Many prairie plants have broad ecological amplitude making the designation of a taxon as a prairie species somewhat arbitrary. For this reason, tallying a total number of vascular plant taxa for the variety of prairie communities is unavoidably imprecise. Nevertheless, an estimate of 800 to 850 plant species for Illinois prairies has been made (82) based on combined lists (e.g., 73, Evers unpublished data, and 88, 89). These lists, however, include several notably uncharacteristic prairie species (e.g. oak and maple species) that were recorded from one or more sites. Although this estimate of plant species richness in Illinois prairie is broad in consideration, it is noteworthy that a similar number of plant taxa (ie., n=862) was estimated for prairie communities for the midwestern United States (90).

Carving up the state's natural vegetation cover has served as an interesting but tragic experiment. The question might be: What effect would reducing the original approximately 20 million acres of prairie in Illinois to a mere 2,496 acres, or 0.01%, have on the overall total number of plant species? It might be expected given this harsh treatment that many of the prairie species would be at risk of extinction or at least extirpation from the state. However, of the 680 plant species considered in danger of extinction in the United States and listed by the U.S. Fish and Wildlife Service as threatened or endangered, only eight are found in Illinois (three-quarters are found in California, Florida, Hawaii, Texas, and Puerto Rico [91]). Seven of these broadly can be considered prairie species:

Mead's Milkweed (*Asclepias meadii*)
Decurrent False Aster (*Boltonia decurrens*)
Dune Thistle (*Cirsium pitcheri*)
Leafy Prairie Clover (*Dalea foliosa*)

Figure 4.16. A) Leafy Prairie Clover (*Dalea foliosa*), a species listed as threatened by the US Fish & Wildlife Service, occurs in a few dolomite prairies in northeastern Illinois. Photo by M. McNicoll. B) Slender Sandwort (*Minuartia patula*), a winter annual species listed as state threatened, is a species of limestone habitats. Populations fluctuate greatly from year to year. Under certain circumstances, colonies can be so dense to appear as local patches in snow in late May. Photo by J. Taft. C) False Mallow (*Malvastrum hispidum*), another annual species of bare dolomite habitats. D) Butler's quillwort (*Isoetes butleri*), a fern ally found associated with shallow soils over dolomite in dolomite prairies in northeastern Illinois. The latter two species are listed as endangered in Illinois. Photos by S. Hill.

Lakeside Daisy (*Hymenoxys herbacea*)
Prairie Bush Clover (*Lespedeza leptostachya*)
Eastern Prairie Fringed Orchid (*Platanthera leucophaea*).

Of these, only the Leafy Prairie Clover is listed as endangered (at risk of extinction throughout range), while the others are listed as threatened (likely to become endangered throughout range).

An additional 67 vascular plant taxa previously known from Illinois are considered to be extirpated from the state (92). Surprisingly, only five of these were possibly prairie species:

Gaillardia (*Gaillardia aestivalis*)
Carolina Phlox (*Phlox carolina* var. *angusta*)
Thismia (*Thismia americana*, an Illinois endemic that probably is extinct)
Wild Blue Larkspur (*Delphinium carolinianum* var. *penardii*; only the variety extirpated)
Prairie Lettuce (*Lactuca ludoviciana*).

With the single exception of Prairie Lettuce, these taxa apparently always were quite scarce in Illinois (93).

About 15% of the native Illinois vascular flora is listed by the Illinois Endangered Species Protection Board (IESPB) as state threatened or endangered, about 339 species at last listing (94). A further unexpected result of the tragic experiment is that only nine of these taxa listed as state threatened or endangered are more or less dependent on silt-loam prairie (93) with an additional 12 taxa occurring in silt-loam prairies as well as other prairie community types (Table 4.2). While few prairie species have been extirpated and relatively few species restricted to silt-loam prairie are listed as threatened or endangered, with broad consideration of all prairie habitats in Illinois, about 103 species (28% of all state threatened and endangered plants) are listed as state threatened or endangered (93). This comprehensive list includes about 12% to 13% of the Illinois prairie flora.

Why has this tragic experiment only cost Illinois citizens five prairie plant species, four of which originally were quite scarce? If the total prairie remaining had been one 2,496-acre parcel in the heart of the Grand Prairie Natural Division, success at retaining diversity with such extraordinary habitat loss would have been far lower. Instead, about 231 much smaller parcels of high-quality prairie occur scattered throughout much of the state (Fig. 4.17) in a variety of prairie habitat types, each with its own unique set of species as well as core species similar to most types. This variety of prairie habitats is the result of diverse ecological conditions found statewide and accounts, to this point, for the sustained richness of the Illinois prairie flora.

This brief overview of prairie communities provides an indication that the prairies of Illinois comprise a diverse assemblage of plant (and animal) species associated with a wide range of ecological conditions. As site geological, topographic, and moisture characteristics influence soil types, so too do they influence species composition with no two sites exactly alike. However, few citizens of Illinois have the privilege of observing this range of prairie types. Scientists and conservationists working to protect, manage, and conduct research on these last remnants of prairie, like canaries in the catbird seat, are keenly aware of their vulnerability. While threats are apparent to these last remnants of tallgrass prairie, resources can be brought together to make sustaining prairie in the Prairie State a long-lasting priority so that more citizens are afforded the opportunity to gain an appreciation of our shared natural heritage.

The hope that such commitment can be made is supported by a growing interest by the general public in restoring and reconstructing prairie habitats (see Chapters 13 and 14). The aesthetic values of prairie landscapes and the potential value of prairie plants in a system of sustainable agriculture is drawing attention from several sources. Efforts are being made to develop one of the native grasses (eastern gamma grass [*Tripsacum dactyloides*]) into a perennial grain crop (95) and to expand the use of warm-season native grasses as a source of forage in combination with cool-season domestic grasses. New initiatives also are examining the potential for tallgrass prairie plantings to serve as biofuels (e.g., 96). Some plantings have been used for

Table 4.2. Plant species found in silt-loam prairie that are listed as threatened or endangered by the Illinois Endangered Species Protection Board (94). * Species also listed by the U.S. Fish and Wildlife Service as federally threatened or endangered.

SCIENTIFIC NAME	COMMON NAME	STATUS
Species of Silt-Loam Prairie		
Elymus trachycaulus	Bearded Wheat Grass	ST
Ascleapias meadii	Mead's Milkweed	SE, FT
Bechmannia syzigachne	American Slough Grass	SE
Boltonia decurrens	False Aster	ST, FT
Camassia angusta	Wild hyacinth	SE
Lactuca ludoviciana	Prairie lettuce	SE
Platanthera leucophaea	Prairie White-fringed Orchid	SE, FT
Sabatia campestris	Prairie Rose Gentian	SE
Sisyrinchium montanum	Mountain Blue-eyed Grass	SE
Species of Silt-Loam and Other Prairie Communities		
Asclepias ovalifolia	Oval Milkweed	SE
Calopogon tuberosus	Grass Pink Orchid	ST
Cypripedium candidum	White Lady's Slipper Orchid	ST
Cypripedium parviflorum	Small Yellow Lady's Slipper Orchid	SE
Cypripedium reginae	Showy Lady's Slipper Orchid	SE
Juncus vaseyi	Vasey's Rush	SE
Phlox pilosa ssp. *sangamonensis*	Sangamon Phlox	SE
Silene regia	Royal Catchfly	SE
Spiranthes vernalis	Spring Ladies' Tresses	SE
Tomanthera auriculata	Auriculata False Foxglove	ST
Tradescantia bracteata	Prairie Spiderwort	ST
Trillium viride	Green Trillium	SE

Figure 4.17. Distribution of prairie remnants recognized as Grade A or B by the Illinois Natural Areas Inventory. Each dot represents a prairie remnant (n = 231).

Figure 4.18. Spring burn at Unity East Grade School Prairie Reconstruction, Champaign County, Illinois. Photo by J. Taft.

erosion control of drainageways and an increasing number of primary and secondary schools are planting prairie as an educational resource (Fig. 4.18).

SAVANNAS AND OPEN WOODLANDS

The topic of savannas might conjure images of scattered acacias and herds of grazing elephants, giraffe, and zebra. But such savannas, reliant on interactions among grazing animals, landscape variables, and fire (97), are not just a feature of African landscapes; rather, they occur throughout many parts of the world including North America and particularly in midwestern states such as Illinois (9, 98). Nevertheless, maps illustrating the dominant vegetation types in Illinois at the time of settlement generally show only two basic formations: prairie and forest (see Fig. 3.7). But the sharp dividing line depicting the boundary between prairie and forest is more a measure of convenience of scale and difficulties in mapping variable boundaries than a reflection of reality. Fires that contributed largely to the maintenance of tallgrass prairie typically did not stop abruptly at a forest border but rather these fires often contributed to the formation of a patchy continuum from open prairie to closed forest termed the prairie-forest ecotone (12, 99, 100).

Some prairie groves (101) may have been exceptions to the prairie-forest continuum because they typically occurred as islands, often dominated by fire-tolerant Bur Oaks, that dotted the Grand Prairie region in Illinois. These occurred in protected areas where fires may have been less regular. Such groves were described as having fairly sharp outlines with few trees extending into the prairie (102). Nevertheless, judging from the compostional and structural changes ongoing in remnant groves (e.g., 103, 104), these also were affected by periodic fire.

Savanna has been defined as a habitat with scattered, open-grown trees, with or without shrubs, and a continuous herbaceous ground cover (105); in the Midwest, these include many species of grasses and forbs also found in prairie. Woodland generally refers to a partially closed canopy, with or without a shrub stratum, and a ground cover including dominance of grass and sedge (graminoid) species, forbs, and woody plants (seedlings and vines) with a greater predominance of species found in ecotonal zones and fewer prairie species. To address the range of structural variation found in the prairie-forest continuum and in prairie groves, for convenience these collectively are referred to here as savannalike habitats. Midwestern savannalike habitats have several unifying characteristics: 1) scattered trees typically with an open-canopy structure (relative to trees in a closed forest); 2) overstory dominance by a few species of oak; 3) a majority of floristic diversity contained in the ground cover, usually rich in species associated with tallgrass prairie and ecotonal zones including grasses, sedges, and forbs; and 4) fire-tolerant species and dependence on fire for maintenance of diversity and stability (9).

CLASSIFICATION AND TRENDS IN SAVANNALIKE HABITATS

Classification of Savannalike Habitats

Several efforts have been made to classify vegetation along the prairie/forest continuum. Distinctions between these major vegetation types can be somewhat arbitrary and have been interpreted in a variety of ways (Fig. 4.19). Vegetation can be classified according to dominant plant species for plant community classification (e.g., bur oak savanna) or growth form and environmental conditions yielding a natural community classification (e.g,. mesic savanna). Because of individualistic species interactions, conservation agencies in the Midwest typically use a natural community system of classification (e.g., 67, 106).

Three basic savanna types (subclasses) are recognized in Illinois (67): *Savanna* (generally on fine-textured soils), *Sand Savanna* (Fig. 4.20), and *Barrens* (Fig. 4.21). Barrens is a term that has been applied to a wide variety of habitats. As used here, barrens refer to local inclusions of a prairielike flora and savanna structure within a predominantly forested landscape. These savanna types are further distinguished by soil-moisture characteristics. These natural communities often occur associated with other vegetation types (e.g., dry to dry-mesic upland forest, flatwoods, prairie) with indistinct boundaries that could vary over time.

Transitions between natural community types, such as from savanna to forest, can be bidirectional depending on fire frequency (Fig. 4.22). Prior to the establishment of the agricultural landscape in Illinois and the resulting isolation of remnant natural communities, transitions among vegetation types were readily facilitated by landscape connectivity and generally unrestrained opportunities for migration among individual plant species. However, the contemporary constraints on species movement due to habitat fragmentation strongly limits the potential species pool (107) and the capacity for bidirectional changes among associated habitats without losses in species diversity. These constraints on floristic relay with vegetational changes are a major concern regarding conservation of savanna and open-woodland habitats.

Savannalike Habitats at the Time of Settlement (Early 1800s)

Savannalike communities form by two basic processes: trees invading prairie with periodic fire absence, and prairie invading woodland during periods of greater fire frequency (Figure 4.22). The presettlement distribution has been estimated for deep-soil, tallgrass savannas (98) and the Eastern Prairie-Forest Transition zone (12). A total area of about 30 million acres of tallgrass oak savanna has been estimated for the Midwest (98). However, neither estimate included the region of the Ozark Plateau, the southern portion of the Illinoian till plain, or the Shawnee Hills region. Considering the vegetation documented in these regions consisting of open woodlands and local inclusions of a prairie flora (108, 109, 110), the extent of savannalike communities considered here expands somewhat beyond the region of tallgrass savanna and transition zone (Fig. 4.23).

Based on distribution of soil types transitional between forest and prairie and detailed county-level presettlement vegetation maps (e.g., 111, 112, 113), savannalike communities, including deep-soil tallgrass savanna (98) and more shallow-soil variants (114), were widespread and relatively common in Illinois. The estimates for total prairie and forest in Illinois (see Fig. 3.7) include most savannalike habitats in the forest category. Areas with very sparse trees (e.g., a few trees per acre) probably were mapped in the GLO surveys as prairie.

Trends Since Settlement

For a time, many settlers continued the aboriginal practice of using broadcast-scale fire on a nearly annual basis, in some cases up to the 1920s when it was considered to be a "savage custom" to be strongly discouraged (115). With the following national campaign of fire suppression featuring Smokey Bear, fire frequency declined precipitously by the 1930s. As an indication of fire dependence, in just a few decades of reduced fire, many savannalike habitats persisting to that time in the Midwest were altered by a conversion to woodland and closed forest (20, 165). Stand closure, a result of increasing tree density, eventually was followed by the patterns of reduced oak regeneration seen today (see Forest section). Understanding the role of fire in the maintenance of oak dominance (116) was not immediately apparent to many foresters and conservationists throughout much of the twentieth century and in some districts remains controversial.

Generally, along the gradient from open prairie to closed forest, there are predictable changes in vegetation structure and composition. For example, the importance of graminoid species declines and woody plant seedlings, saplings, trees, and vines increase (117). A principal difference between tallgrass savanna and open woodland communities is the composition of matrix graminoid species. While many of the dominant prairie grasses (e.g., Big Bluestem, Indian Grass, Little Bluestem, and Porcupine Grass [*Stipa spartea*]) were important in open savannas (other than *Stipa*, these are warm-season species with the C4 photosynthetic pathway), woodlands are more characterized by the presence of somewhat more shade-tolerant grasses (i.e., cool-season species with the C3 photosynthetic pathway) such as Wood Reed *(Cinna arundinacea)*, Bottlebrush Grass *(Elymus hystrix)*, Woodland Brome *(Bromus pubescens)*, several panic grasses *(Dichanthelium* species), and several sedges (e.g., *Carex pensylvanica, C. albicans, C. muhlenbergii, C. hirsutella*). The transition from prairie-grass dominance to woodland-grass/sedge dominance can be abrupt, suggesting prairie grasses share a common threshold of shade tolerance (118). The accumulation of litter with increasing density of trees is known to reduce the yield of shoots and favor rhizomatous mid grasses compared with bunch grasses dominant in prairies (119). These compositional characteristics provide a gauge for interpreting transition phases in the prairie-forest continuum. Along this continuum from full sun to light-limited communities (e.g., prairie to forest), there is a shift in competition and resource allocation patterns among plants from primarily below ground (roots) to primarily above

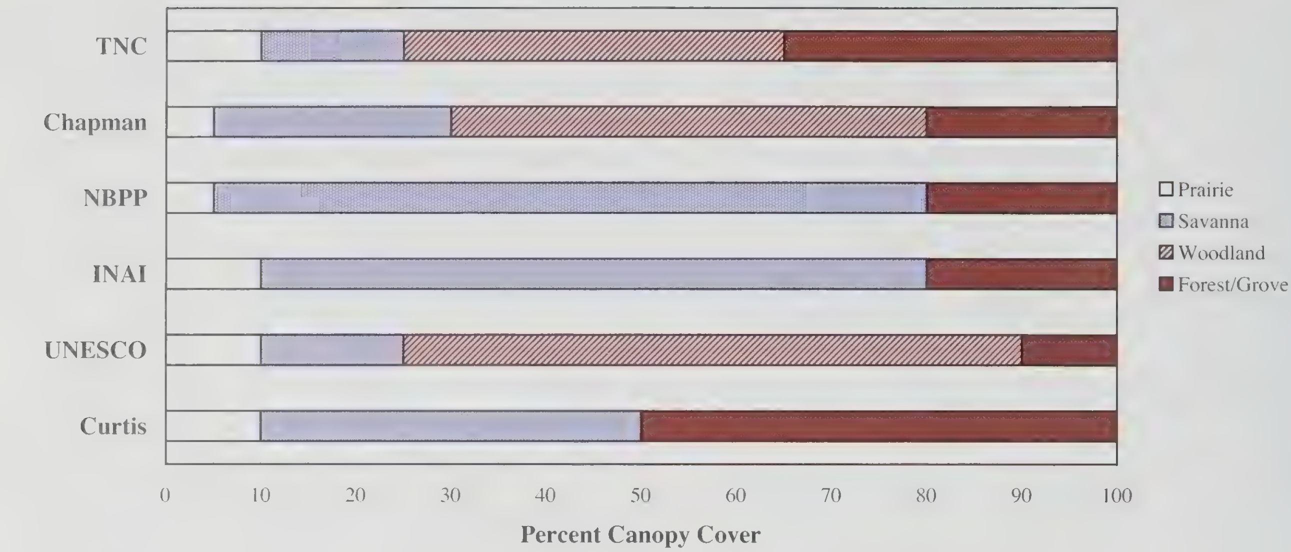


Figure 4.19. Classification schemes for prairie, savanna, woodland, and forest communities according to percent canopy cover (modified from 9). TNC = The Nature Conservancy, NBPP = North Branch Prairie Project, INAI = Illinois Natural Areas Inventory.

Figure 4.20. Sand savanna dominated by Black Oak (*Quercus velutina*) at Illinois Beach State Park, Lake County, Illinois. Photo by J. Taft.

Figure 4.21. Gibbons Creek Barrens, a dry barrens community in Pope County, Illinois. Photo by J. Taft.

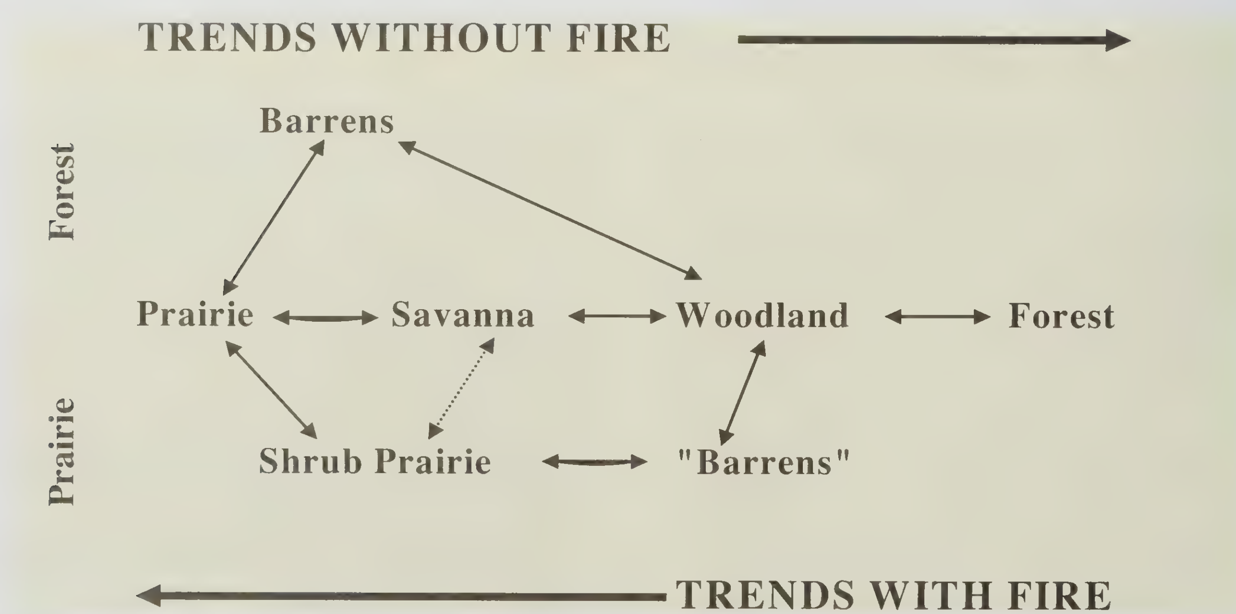


Figure 4.22. Diagram of habitat transitions with and without fire in forested vs. prairie regions. The trends imply increasing or decreasing fire frequency (modified from [9]).

ground (120). Fire often is prescribed to reverse these trends (see Chapter 14) by reducing litter accumulation and the density of woody plants and their shading effects.

The extent of a shrub-sapling layer in savannalike communities can provide a gauge to recent fire history. With reduced fire frequency, a shrub/sapling stratum typically formed including hazel, plums, sumacs, poplars, and oaks (87, 108). In places, large shrub and oak grub-dominated (oak resprouts) thickets were characteristic of transitional zones between savanna and prairie (121, 122, 123). Hazel remains a common species in closed oak woodlands throughout Illinois; however, no reproduction occurs in dense shade. These contemporary sterile populations probably represent remnants from past hazel thickets overtaken by the forest and thus could be considered artifacts of the former disturbance-mediated savanna/open woodland ecosystem.

Savannalike communities, perhaps more than other vegetation types, have been greatly changed as a result of habitat fragmentation and altered natural disturbance cycles. Foremost among these alterations has been a decline in fire frequency, resulting in at least partial transition towards closed woodland and forest habitats at many sites. Consequent to these changes, the once widespread oak savannas have become among the rarest plant communities in the Midwest (98).

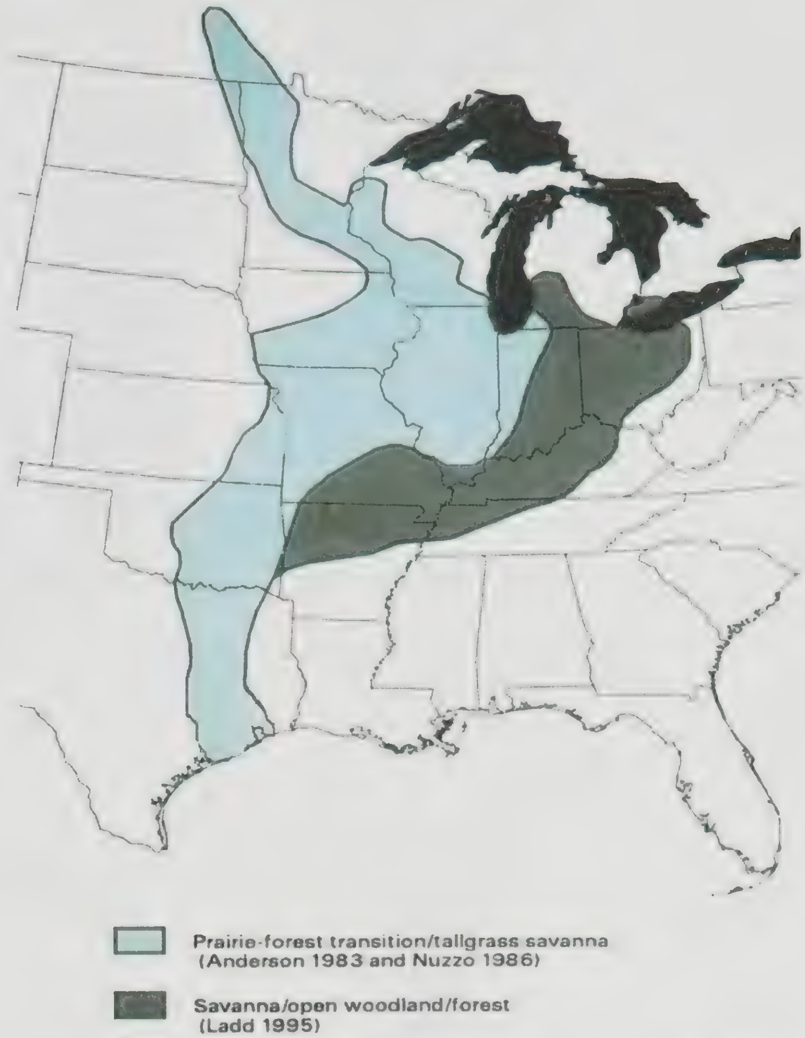


Figure 4.23. Distribution of the prairie-forest and savanna/open woodland transition zones in midwestern North America (modified from 9).

CONTEMPORARY STATUS OF SAVANNALIKE COMMUNITIES

Tallgrass savannas in several midwestern states have been estimated to include 113 noteworthy sites totaling 6,442 acres of relatively high-quality tallgrass savanna habitat, about 0.02 % of the estimated previous extent (98). Presently in the Midwest, former savanna and open-woodland habitats still can be recognized on sites with rich silt-loam soils by the scattered occurrence of large, open-grown oaks often now within closed woodland. In addition to these relicts, local features of surface geology have contributed to the persistence of savannalike habitats. Droughty conditions found where sand deposits are located and where bedrock is near the surface, typically where bluffs occur along the major rivers and in unglaciated regions, have retarded vegetational changes during extended periods of fire absence. Because these environmental conditions limit agricultural use, similar to prairies described previously (Fig. 4.10), such areas are disproportionately represented among natural savanna remnants (Fig. 4.24). For example, the Illinois Natural Areas Inventory (INAI) has delineated only 87 acres among nine sites of relatively undisturbed savanna on silt-loam soils compared with a total of 1,204 acres among 16 sites on sandy soils (65, 124). The INAI also identified 132 acres of dry to mesic barrens at 19 sites. Of these 44 savannalike remnants totaling 1,424 acres, sites on deep silt-loam soils account for only 6.1% of total area and 20% of remnants. Most savanna remnants are small and in the one- to five-acre range; however, 14 sites (32% of total) have been identified that are greater than 20 acres (Fig. 4.25). Most of these larger savannas (79%) are on sandy soils. In addition to these natural areas, many savannalike areas have been structurally maintained or created by livestock grazing (Fig. 4.2). Typically, the ground cover at pastured sites is degraded and characterized by an abundance of non-native species.

Despite widespread habitat loss and degradation, field botanists in the Midwest have empirical knowledge of characteristic species of savannalike habitats (Table 4.3). As with findings in Wisconsin where only six species were found to be typical of oak openings (20), few of the species in Table 4.3 are limited to savannas. Rather, many have broad ecological amplitude occurring also in prairie, woodland, and other habitats. As a result, few savanna species of the Midwest are globally rare (none are listed by

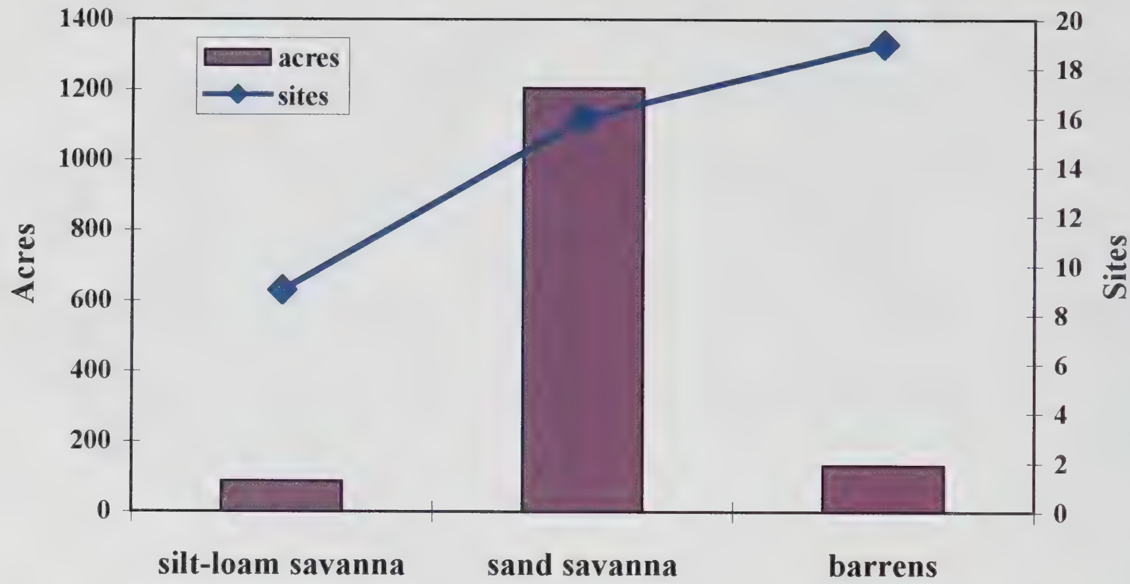


Figure 4.24. Sum acreage and site number of high-quality savannas recognized by the Illinois Natural Areas Inventory showing data by savanna subclasses.

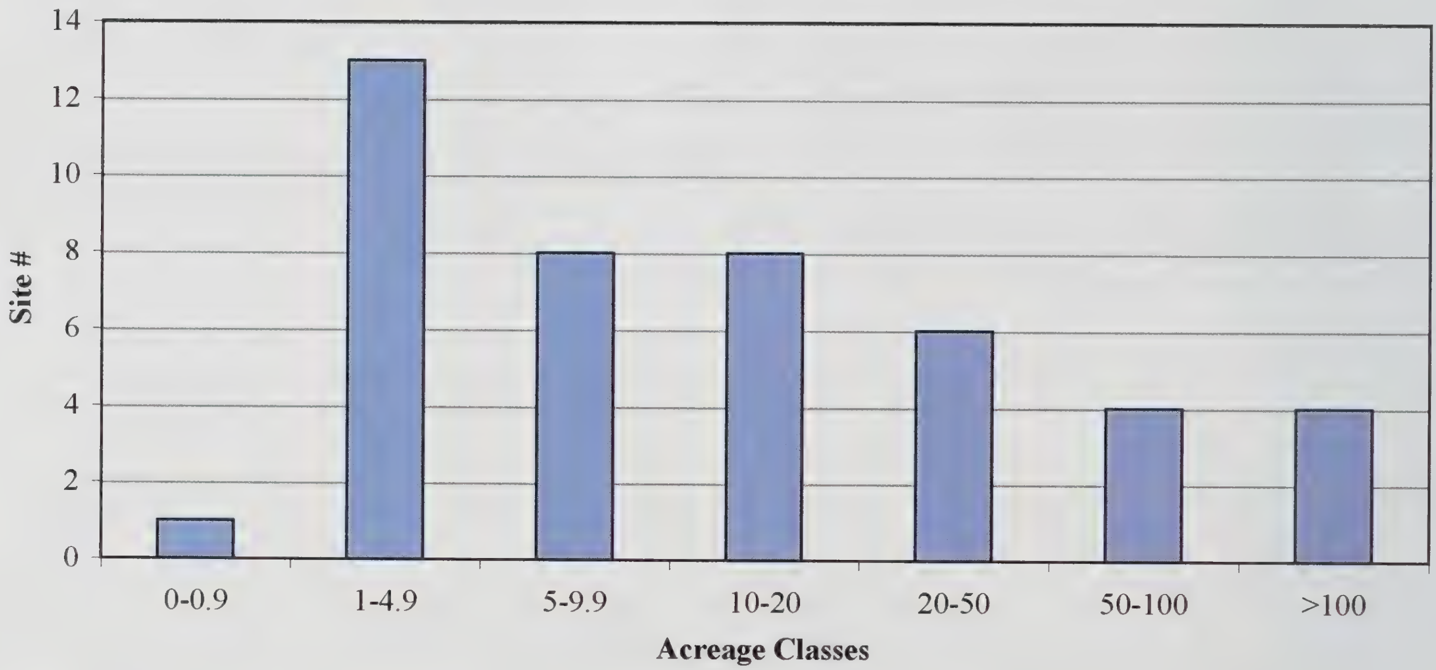


Figure 4.25. Size-class distribution among sites for high-quality savanna remnants recognized by the Illinois Natural Areas Inventory.

Table 4.3. Select list of 50 characteristic species of savanna and open woodland habitats. Species listed as state threatened (ST) and State endangered (SE) are indicated. Species indicated by S are characteristic in sandy soils. Note that these species, while occasionally found in other habitats, signal savanna. Many other important savanna species (e.g., prairie grasses) are not listed because their presence does not necessarily suggest savanna since they occur regularly in other community types (e.g., prairie or forest).

Common Name	**Scientific Name**
Bird's Foot Violet	*Viola pedata* - S
Black-Jack Oak	*Quercus marilandica*
Blue Toadflax	*Linaria canadensis* - S
Blunt-Leaf Sandwort	*Moehringa lateriflora*
Buffalo Clover	*Trifolium reflexum* (ST)
Canadian Milk Vetch	*Astragalus canadensis*
Culver's Root	*Veronicastrum virginicum*
Dwarf Bindweed	*Calystegia spithamaea*
False Dandelion	*Krigia biflora*
False Sunflower	*Heliopsis helianthoides*
French Grass	*Psoralea onobrychis*
Goat's Rue	*Tephrosia virginiana* - S
Hairy Bedstraw	*Galium pilosum*
Hairy Meadow Parsnip	*Thaspium barbinode*
Hairy Mountain Mint	*Pycnanthemum pilosum*
Hairy Wild Lettuce	*Lactuca hirsuta*
Hazel	*Corylus americana*
Indian Physic	*Porteranthus stipulaceus*
Kittentails	*Besseya bullii* - S (ST)
Large Ground Plum	*Astragalus crassicarpus* var. *trichocalyx* (SE)
Mullein Foxglove	*Dasistoma macrophylla*
New Jersey Tea	*Ceanothus americanus*
Pale Indian Plantain	*Cacalia atriplicifolia*
Pale Vetchling	*Lathyrus ochroleucus* (ST)
Pennsylvania Oak Sedge	*Carex pensylvanica*
Post Oak	*Quercus stellata*
Purple Coneflower	*Echinacea purpurea*
Purple Milkweed	*Asclepias purpurescens*
Round-Fruited Panic Grass	*Dichanthelium sphaerocarpon*
Royal Catchfly	*Silene regia* (SE)
Sangamon Phlox	*Phlox pilosa* subsp. *sangamonensis* (SE)
Savanna Blazing Star	*Liatris niewlandii* (ST)
Shooting Star	*Dodecatheon meadia*
Slender-Leaved Panic Grass	*Dichanthelium linearifolium* - S
Spreading Dogbane	*Apocynum androsaemifolium* - S
Starry Campion	*Silene stellata*
Sweet Fern	*Comptonia peregrina* (SE)
Tall Alumroot	*Heuchera americana*
Tall Forked Chickweed	*Paronychia canadensis*
Thicket Parsely	*Perideridia americana*
Upland Boneset	*Eupatorium sessilifolium*
Violet Collinsia	*Collinsia violacea* (SE)
Virginia Spiderwort	*Tradescantia virginiana*
Wild Hyacinth	*Camassia scilloides*
Wild Lupine	*Lupinus perennis* - S
Wild Quinine	*Parthenium integrifolium*
Wolf's Bluegrass	*Poa wolfii* (ST)
Wood Angelica	*Angelica venenosa*
Yellow Pimpernel	*Taenidia integerrima*

the USFWS as threatened or endangered) although many are regionally scarce and listed as state threatened or endangered (Table 4.3). For this reason, much of the conservation focus on savannas is at the community level rather than a focus on individual species recovery. However, capturing and preserving the dynamic spatial heterogeneity of savannalike systems within set preserve boundaries is particularly challenging in a highly fragmented landscape. In small reserves of fire-dependent savannalike natural communities, habitat may not always be available for species dependent on a particular stage in the dynamic continuum (125). Such reserves are likely to require intensive management activities that maintain or enhance population sizes, existing levels of diversity, and prevent vegetational changes from greatly altering the preserve target community (126).

FOREST

Since the early 1800s, Illinois' forests have undergone dramatic changes in total extent as well as habitat composition and structure. Few if any areas remain that have not been cut, grazed, or altered by land-use activities. Fires that previously were commonplace in prairie and savanna habitats also entered forests influencing species composition and stand structure; however, extensive periods of fire absence have led to major changes in current forests. Among the compositional changes has been a shift from oaks to more shade-tolerant maples and elms. Furthermore, many non-native species have invaded and become invasive, leading in some cases to replacement of native forest species. This section describes these trends in two parts. Part I provides an overview of spatial trends from the time of European settlement to the present, including overstory species regeneration dynamics and protection status of remaining forests. Part II summarizes major forest community types found in Illinois including current forest composition, diversity, and health. Chapter 15 of this volume describes selected results from the forest monitoring component of the Critical Trends Assessment Program. Chapter 16 describes how tree species might respond to climate warming based on a series of predictive models.

PART I—FOREST TRENDS

Forests at the Time of European Settlement (Circa 1820)

At the time of the first European-American settlements in Illinois, woodlands and forests covered about 15.3 million acres, or 42% of the land area, more than triple the current extent. As noted in Chapter 3, Illinois was systematically surveyed by the General Land Office during the period 1807–1844, establishing the familiar coordinate system of Township, Range, and Section. Surveyors, starting with southern Illinois and working northward, primarily were charged with dividing the land into sections and townships; however, they also prepared plat maps and made notes on the vegetation they encountered. These data provide unique insights to the appearance of the landscape and the distribution of forest and prairie prior to the extensive land cover alterations that followed settlement. Large expanses of forest existed at the time of Euro-American settlement with the greatest concentrations in the western and southern regions (see Fig. 3.7). However, based on the boundaries of the current 102 Illinois counties, most had some forest area. Only 21 counties, all in the Grand Prairie Natural Division (see Chapter 2), had less than 20% forest cover.

Forests, particularly upland stands, at this time differed from most current stands by their exposure to occasional fires. Oaks, including potentially 13 of the 20 species native to Illinois, were dominant in the overstory of upland areas (the remaining species primarily are bottomland species). Oaks greater than a few inches diameter are capable of enduring low-intensity fires typical of woodland/forest stands, favoring their dominance and ecological significance. In contrast, maples are favored in more closed and shaded stands and, when young, tend to be fire sensitive. According to the early surveyor records, Sugar Maples were quite scarce compared with modern forests (127), suggesting fire was a widespread and general phenomenon. The spreading form of old oaks in the few remaining old-growth stands is a reminder of the formerly more open conditions that existed when these trees became established.

Characteristics of the landscape had great influence on forest distribution in Illinois. Forests primarily were concentrated in areas of greater topographic relief such as the dissected terrain of riparian corridors where there was some fire protection (52). For example, about three-quarters of all forest cover in Illinois is associated with slopes greater than 4%. In contrast, most prairie vegetation (82.3%) occurred on landscapes with less than 4% slopes (7). Most of the timbered land associated with this low-slope category occurred in floodplains or the formerly extensive flatwoods of the Illinoian till plain (described in Part II).

Forest Trends Since Settlement

Extensive forest clearing, grazing by livestock, fire absence, and shifts in native species composition, as well as exotic species infestations, have greatly altered Illinois forests since the early 1800s. Only about 16,452 acres of forest land remains in a relatively undisturbed condition (65, 124 updated in 2007), about 0.1% of the acreage at the time of settlement. In other words, 99.9% of forest lands have been altered appreciably, though some have recovered somewhat from past disturbances. As a result, together with the near complete elimination of prairie (see Prairie section) and dramatic losses of wetland acreage (see Chapter 5), Illinois ranks 49th among the 50 states, next to Iowa, in the percent of land converted from its potential vegetation type (128, 129).

The pattern of deforestation of primary forests in Illinois can be deduced by the estimates of forest land cover in the early 1800s and in periodic forest surveys comprehensively beginning in 1924 (Fig. 4.26) and following accounts (e.g, 130, 131, 132, 133). Many early settlers mistakenly believed the prairies were too infertile to support trees, thus forests at first were the primary lands utilized for agriculture. However, with the development of the steel, self-scouring moldboard plow, settlers discovered that prairies could be cultivated and made productive cropland. Subsequently, prairies were converted to cropland

at an astonishing rate (see Prairie section). Over 300,000 people settled in the prairie regions during the 1830–1840 period, and since railways were not yet in place, local timber supplies were utilized extensively for housing material, fuel, and fenceposts. Most of the timber in the prairie counties disappeared during this period.

By 1860, the timber industry began to flourish in Illinois. By 1870, 92 of the 102 counties had manufacturing industries based on wood products and total forestland in the state had been reduced to an estimated 6.02 million acres (130), 39% of original coverage. During the 1880s, total annual lumber production within Illinois reached over 350 million board feet, or 2.2 times the present rate (Fig. 4.27). Lumber production continued to increase until 1880, after which it began to decrease due to limited resources. By 1923, only about 22,000 acres of the original 15.3 million acres of primary forest remained, although because of regrowth from timbered stands, total acreage was just over 3 million acres. Late nineteenth century deforestation rates in Illinois compare with, or in some cases exceed, late twentieth century deforestation rates in tropical areas such as the Rondonia region of Brazil and Malaysia (134). History (in this case, unsustainable extraction of natural resources) does indeed repeat itself.

Forest area in Illinois reached its minimum extent in about 1920 with 8.5% statewide coverage (22% of presettlement acreage). During the next 80 years, area of forest land cover increased by about 50% (130, 132) to 4,525,300 acres (Fig. 4.26) with the greatest increase during the period from 1924 to 1948. Total forest cover in 2005 was about 12.7% of the state. This trend partially can be attributed to a reduction in cattle grazing and conversion of pastures and hayfields to forest. In 1998, 11% of timberlands (excluding protected forest acreage) also were used as pasture, down from about 14% in 1985, leading to improved rates of canopy tree regeneration. Grazing in forest habitats by domestic livestock such as cattle can be destructive, affecting not only tree regeneration but also tree growth, tree mortality, and water quality (132). While a relatively small percentage of forest land currently is grazed, it is hard to find forests in Illinois that do not bear the signature effects of cattle grazing. Perhaps most salient is the effect on understory vegetation, yielding a composition dominated by weedy native and non-native species known as grazing increasers such as (* = non-native species):

Black Snakeroot (*Sanicula odorata*)
White Snakeroot (*Eupatorium rugosum*)
Pokeweed (*Phytolacca americana*)
Enchanter's Nightshade (*Circaea lutetiana*)
Missouri Gooseberry (*Ribes missouriense*)
Black Raspberries (*Rubus allegheniensis, R. pennsylvanica*)
Multiflora Rose* (*Rosa multiflora*)
Amur Honeysuckle* (*Lonicera maackii*).

The effects can be so long lasting that such woodlands have been described as being in a state of botanical purgatory (135). Over-abundant White-tailed Deer continue these destructive effects today.

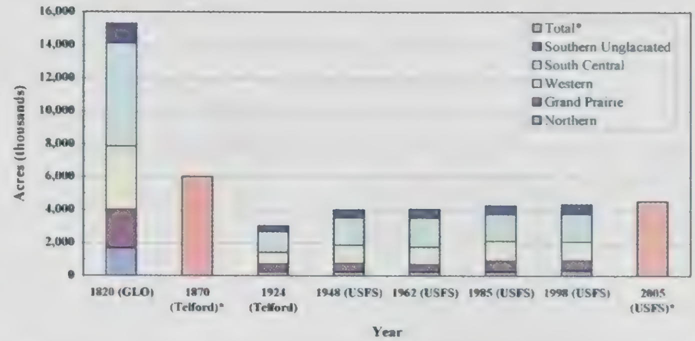


Figure 4.26. Area of forest land in Illinois by region since European settlement. *regional data not available. For a map of regions, see (137).

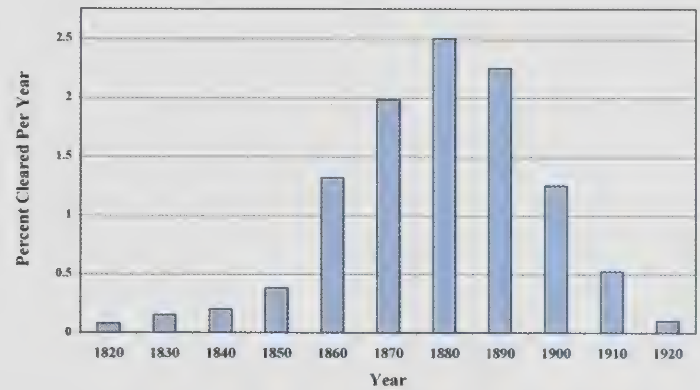


Figure 4.27. Estimated rate of forest clearing and lumber production statewide in Illiniois from 1820 to 1920. Source: 137.

The Current Status of Illinois Forests

The current forest area in Illinois of about 4,525,300 acres is 29.6% of the presettlement (1820) extent (Fig. 4.26). This amount reflects a gradual increase, about 0.087% annually, from the lowest extent a century ago. While modest, this increased forest land is a dramatic difference from the peak harvest period of the late 1800s (Fig. 4.27). Most forest in Illinois (82%) occurs on private lands followed by federal, corporate, state, and local government land holdings (Fig. 4.28). Of the current total forest area, most is upland forest and about 18% is bottomland forest and swamp (136).

The dominant age classes in 1998 for forest parcels in Illinois are in the 41–60 year range (Fig. 4.29). Although this appears to be a contrast from 1985 when the most prevalent forest areas were in the 61 to 80-year range (137), the differences are attributable to a revised analytical approach that now considers understory trees in assessing stand age characteristics (132). As with the analysis based on 1985 data, the proportion of oak-hickory forest types remains much greater in the older age classes while maple-beech and elm-ash-cottonwood forest types proportionately are much more important in the younger age-class stands (Fig. 4.29).

Another method of measuring forest resources besides area coverage is by volume of growing stock based on biomass estimates. This takes into account both area and tree size. Total net volume of growing stock in Illinois forests increased 109% from 1962 to 2005 (Fig. 4.30). The

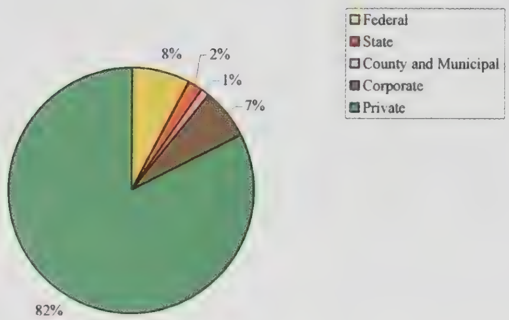


Figure 4.28. Area of timberland by ownership class as of 2005. Total timberland area at time of survey was 4,087,000 acres. Source: (132).

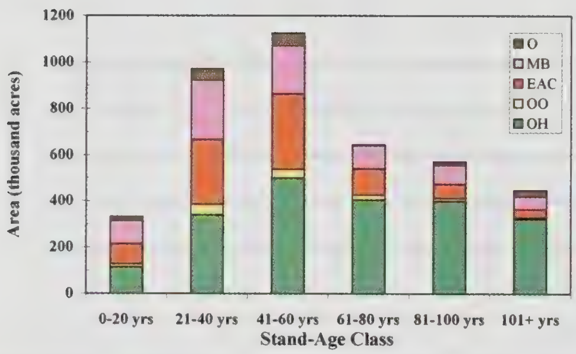


Figure 4.29. Distribution of size-classes by total area of forest types in Illinois. Source: (132). O = oak, MB = maple-beech, EAC = elm-ash-cottonwood, OO = oak and other , OH = oak-hickory.

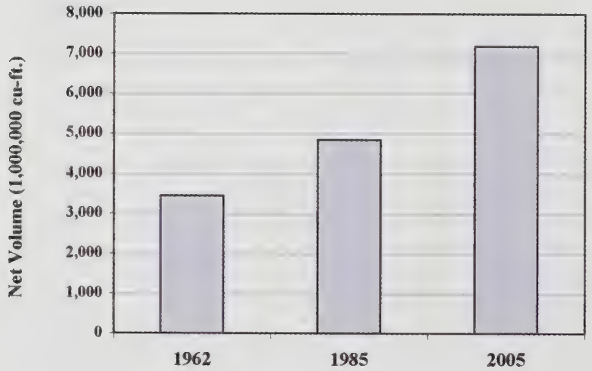


Figure 4.30. Total net volume of timberland growing stock in Illinois. Source: (131, 133).

volume of softwoods has increased over 800% since 1962 as area and age of pine plantations have increased; however, softwoods remain a minor component of total forest land biomass (Table 4.4). The greatest total volume of growing stock is among oaks because of their continued overall dominance in larger size classes (Fig. 4.31). Percentage increases for oak species ranged from 64% to 75% for White and Red Oak species groups, respectively. Hickories (*Carya* spp.) were next in total volume of growing stock, increasing 113% between 1962 and 2005; soft maple (primarily *Acer saccharinum*) ranked third in total growing stock volume among identified species groups and showed an increase of 150%. The largest percent increase in net volume growing stock was among Yellow Poplar (*Liriodendron tulipifera*) with a 359% increase from 1962 to 2005 (Table 4.4). Trends in total area for forest types show prominent changes from 1962 to 1985 (137) with oak-hickory and elm-ash-cottonwood forest types declining in area while maple-beech had a 12-fold increase. By 1998, the last year of comparable data from the USDA Forest Inventory and Analysis program (132), the oak-hickory forest type appears to have stabilized while there is some increase in elm-ash-cottonwood and modest decline in total area of stands classified as maple-beech forest (Fig. 4.32).

Regional patterns differ with regard to forest increase and decrease between 1962 and 1998 (Fig. 4.33). Many counties, particularly in the northern half of the state, show dramatic increases in forest acreage. Counties with net decline in acreage mostly are concentrated in the region of the Illinoian till plain. Decline is particularly concentrated in counties bordering the lower Kaskaskia River. Forests bordering the lower reaches of the Kaskaskia River form one of the largest contiguous blocks of forest remaining in the state, most of it privately owned. Continued logging in this region likely will lead to fragmentation of this large forest block.

Forest Fragmentation—Habitat conversion has led to extensive fragmentation of forest habitats in Illinois and this fragmentation has consequences for both plant and wildlife species. For example, neotropical migrant birds require large blocks of uninterrupted forest for successful nesting habitat (138) and predators such as Bobcats also require large unbroken tracts of forest (see Chapter 6). Edge zones of forest fragments also can be environmentally and biologically distinct from interior zones, particularly south and west-facing aspects where, compared to forest interior areas, wind and light exposure is greater, humidity lower, and a distinct floristic composition (139). An analysis of the distribution of forest patch sizes in Illinois determined there were 10,121 forest parcels greater than 40 acres (the minimum detectable size in the analysis) and the average patch size was 358 acres (137). These fragments accounted for 85% of forest acreage in Illinois while the remainder occurred in numerous fragments < 40 acres. Most fragments identified (> 40 acres) were in the 40–100 acre range (45%) and only 10% were larger than 600 acres (Fig. 4.34). Most INAI forests (high-quality, Grades A or B) are in the 20- to 50-acre range (Fig. 4.35).

Immigration of forest species into fragments, especially plants, is limited by the nature of the surrounding landscape and distance to nearest similar habitat. Maintenance of a species pool is dependent on immigration opportunities to compensate for population declines occurring as a result of disturbance of other factors. As forest fragments become smaller and more isolated, immigration opportunities become more and more limited to weedy native and adventive species that are predominant in the landscape. Maintenance of a viable pool of native species is one of the chief objectives in habitat conservation. With the majority of forest lands in private ownership (Fig. 4.28), this highlights the important role individual private landowners, landowners associations, and conservation groups can play in the maintenance of Illinois' native biodiversity.

Tree Species Regeneration, Fire, and the Maintenance of Oak—The state tree of Illinois is White Oak (*Quercus alba*), an appropriate choice given its statewide distribution and dominance as a canopy species in many upland forests throughout the state. However, many forests on upland sites show an alarming trend—there is insufficient regeneration of canopy species, particularly White Oak (132), to sustain oak dominance in many Illinois forests. Oak seedlings may be present, and a few small saplings, but very few individuals are surviving to larger sizes (140, 141). Oaks in general do not thrive under shaded conditions (most are classified as shade intolerant or intermediate) and increasingly shaded conditions can lead to conversion of forest types from predominantly oak-hickory to dominance by other species such as the elm-ash-maple group (142, 143, 144). For example, the decline of the oak-hickory forest type observed in statewide forest inventory data from 1962-1985 (Fig. 4.32) was attributed to the maple take-over phenomenon (137).

These trends of poor oak regeneration and increases among shade-tolerant species such as Sugar Maple can be linked to a decline in fire frequency in the highly fragmented modern landscape, particularly when compared to previous fire-return intervals such as before and during early periods of settlement (115, 141, 144). While recent trends appear more promising for total area of oak-hickory forest in Illinois (Fig. 4.32), throughout the eastern U.S. including Illinois, data continue to suggest oak regeneration is limited (145, 146, 147, 148). Reasons to sustain oak forests are many. Prominent among them is their significant ecological importance in an evolutionary context, the value of oak timber for fuel, building, furniture, and visual appeal, and the fact that oak forests provide essential habitat for a multitude of wildlife and plant species (149).

These patterns of forest regeneration are not uniform from site to site. Differences exist depending on habitat conditions and site history. Oak regeneration typically is poor to marginal in mesic to dry-mesic stands and thus these can be considered compositionally unstable. However, on dry open woodland sites oak regeneration actually can be excessive leading to a structurally unstable stand. Local variation within the same forest type can be attributed to different disturbance histories. Due to a wave of regeneration of mesophytic species (those with intermediate moisture reqiurements), many forest stands can be described as both compositionally and structurally unstable (see SIDEBAR—Tree Recruitment Patterns).

Increased shading as a result of take over by maple and/or other species has been shown to result in declines in diversity in the ground-cover stratum (93, 141, 150), particularly in upland forests, woodlands, and savannas which support many light-dependent herbaceous species. This attrition of species diversity has particular ramifications in a highly fragmented landscape where opportunities are limited for immigration of species to compensate for declining diversity. In some cases, shading is so great that the forest floor is bare but for leaf litter.

Tree Recruitment Patterns—Tree recruitment trends can be seen in tree size classes when data are from similar habitat conditions. A forest stand is considered self-sustaining and compositionally stable when dominant species show a reversed J-shaped curve among size classes (i.e., many more small diameter trees than large-diameter trees). However, throughout Illinois and elsewhere in the Central Hardwoods Region, the pattern of oak regeneration suggests that under current conditions, we can expect a decline in the importance of oaks in future forests. Trends in an old-growth oak grove (Baber Woods Nature Preserve) show increasing importance of Sugar Maples and other species in small-to-medium size classes and declining regeneration of the canopy-dominant oaks (Fig. 4.36). A forest survey throughout Kendall County in Illinois provides an example of compositional and structural instability. While oaks are dominant among the larger canopy trees, there are few in the smaller size classes; rather, there is a proliferation of species mostly absent from the larger size classes (Fig. 4.37). Oak regeneration differs among dry-mesic upland forest parcels at Beaver Dam State Park (BDSP). Some units, particularly those included in a fire-management program, show some regeneration of oaks while many other species predominate the small size classes (Fig. 4.38). Other units at BDSP demonstrate both compositional and structural instability (Fig. 4.39). In contrast, regeneration of trees in the White Oak group (particularly Post Oak [*Quercus stellata*]) in dry sandstone barrens in southern Illinois is typical of a compositionally stable (oak will continue to dominate) but structurally unstable community (Fig. 4.40) since the openness of the habitat (including prairie species) likely would decrease without intervention such as prescribed fire (see Chapter 14).

Illinois Natural Areas Inventory (INAI)—The INAI (65) established criteria for grading forest quality based on standards including a minimum stand age (90 years or older), size (with rare exceptions, minimum of 20 acres), and ecological integrity (limited disturbance from grazing, logging, or other anthropogenic sources of habitat degradation). The INAI identified 149 forest parcels statewide meeting these criteria (graded A or B [see Chapter 2]) totaling 16,452 acres, about 0.36% of total remaining forest (124). These include 3,718.6 acres of Grade A (essentially undisturbed) and 12,733.5 acres of Grade B forest remnants (slightly disturbed). Of these high-quality stands, about 9,133 acres (55%) are floodplain forest communities, and the majority of high-quality stands of all types range in size from 20 to 50 acres (Fig. 4.35). High-quality remnants were found in 60 of the 102 counties statewide. Lake and St. Clair counties contain the largest

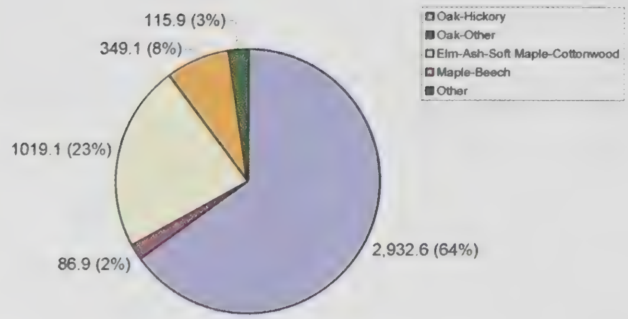


Figure 4.31. Area of forest types in Illinois based on U.S.D.A. Forest Inventory and Analysis data. Source: (133).

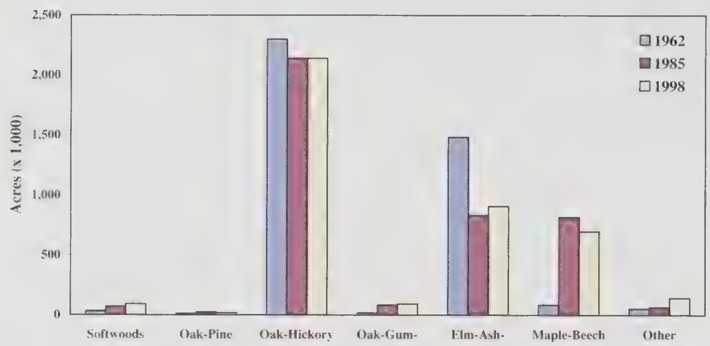


Figure 4.32. Trends in aerial extent of forest types comparing Forest Inventory and Analysis data from 1962, 1985, and 1998. Source: (131, 132).

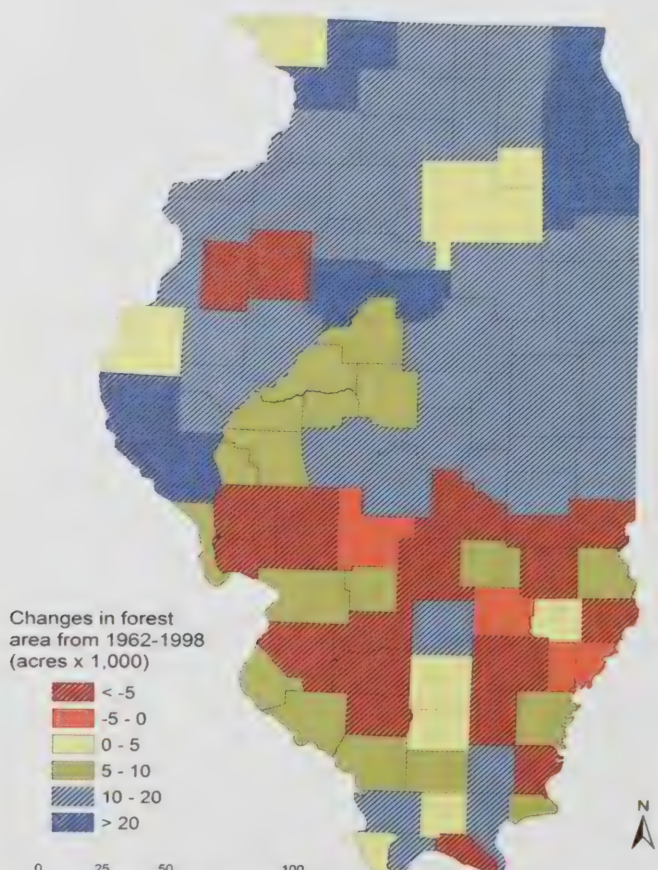


Figure 4.33. Changes in forest area by county (acres x 1,000) based on 1962 and 1998 data. Data source: (132, 151).

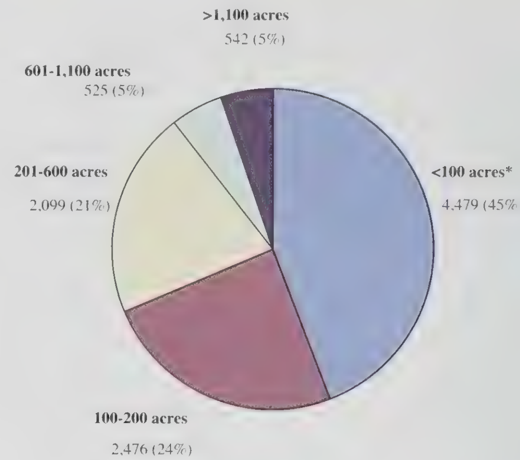


Figure 4.34. Parcel numbers by land-area classes for forest land in Illinois. *Minimum detectable size in analysis was 40 acres. Source: (137).

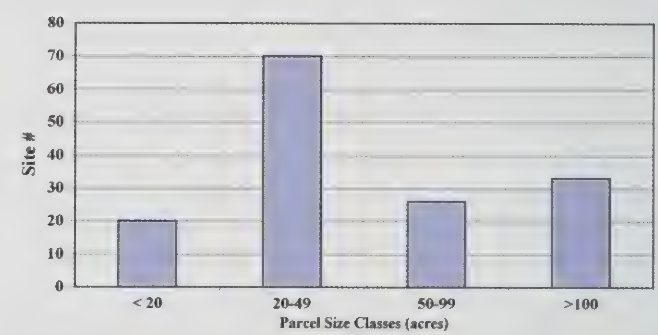


Figure 4.35. Size distribution of Grade A and B forest parcels recognized by the Illinois Natural Areas Inventory (INAI).

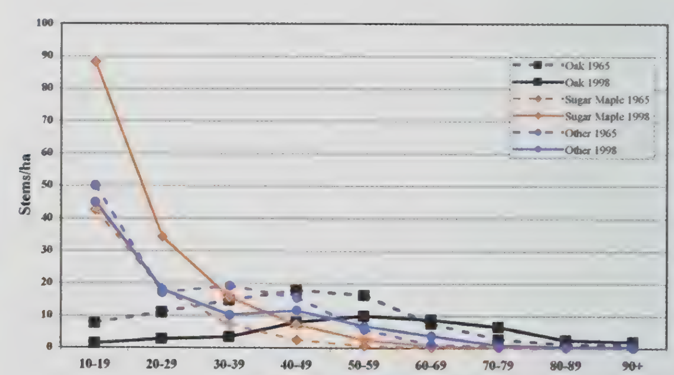


Figure 4.36. Size-class distribution of trees at Baber Woods Nature Preserve, Edgar County, Illinois comparing trends in 1965 and 1983. Source: (162).

Table 4.4. Net volume (thousand cubic feet) of growing stock on forestland in Illinois by species group for 1962, 1985, and 2005. Source: 131, 133, 137). [1]Included in Other Softwoods in 1962 survey. [2]Included in Other Hardwoods in 1962 survey.

Softwoods	1962	1985	2005	Change (1962–2005)	% Change
Loblolly-shortleaf Pine	15,200	64,700	69,854	54,654	360
White Pine[1]	-	16,800	83,615	-	-
Red Pine[1]	-	12,000	20,064	-	-
Eastern Red Cedar	2,400	11,400	31,788	29,388	1,225
Bald Cypress	6,800	8,900	7,009	209	3
Jack Pine[1]	-	700	5,181	-	-
Other Softwoods	700	3,00	11,577	10,877	1,554
TOTAL SOFTWOODS	25,100	117,500	229,088	203,988	813
Hardwoods					
Red Oak	701,800	1,062,400	1,230,774	528,974	75
White Oak	739,700	1,017,600	1,210,108	470,408	64
Other Hardwoods	223,100	203,500	670,690	447,590	201
Hickory	343,900	522,500	733,857	389,957	113
Soft Maple	259,200	341,600	648,333	389,133	150
Cottonwood spp.	114,100	157,800	299,2	185,105	162
Hard Maple	99,800	163,100	260,003	160,203	161
Ash	218,200	261,000	373,923	155,723	71
Sycamore	123,300	134,600	261,148	137,848	112
Black Walnut	77,500	119,100	209,585	132,085	170
Yellow Poplar	26,400	51,800	121,094	94,694	359
Basswood	25,800	54,100	63,829	38,029	147
Sweetgum	58,600	45,100	87,125	28,525	49
Tupelo & Black Gum	13,900	28,000	20,239	6,339	46
Beech	14,500	12,100	15,385	885	6
Aspen spp.	9,100	1,900	4,820	-4,280	-47
Elm	367,700	267,400	292,836	-74,864	-20
Hackberry[2]	-	93,500	202,883	-	-
Black Cherry[2]	-	87,700	149,238	-	-
Willow[2]	-	50,300	64,421	-	-
River Birch[2]	-	36,800	40,379	-	-
Butternut[2]	-	5,700	1,329	-	-
TOTAL HARDWOODS	3,416,600	4,717,600	6,961,204	3,544,604	104
TOTAL ALL SPP.	3,441,700	4,835,100	7,190,292	3,748,592	109

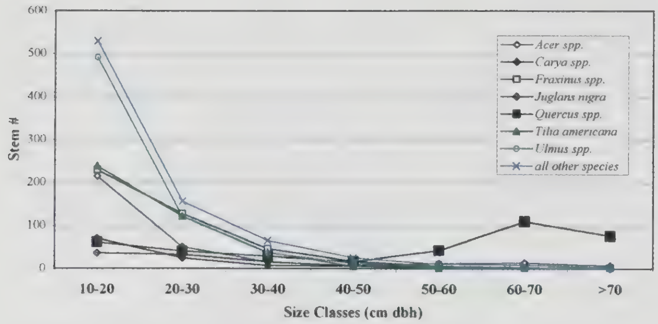


Figure 4.37. Size-class distribution of trees based on 135 0.05-ha forest sampling plots throughout Kendall County, Illinois. Most oak recruitment is Red Oak (*Quercus rubra*).

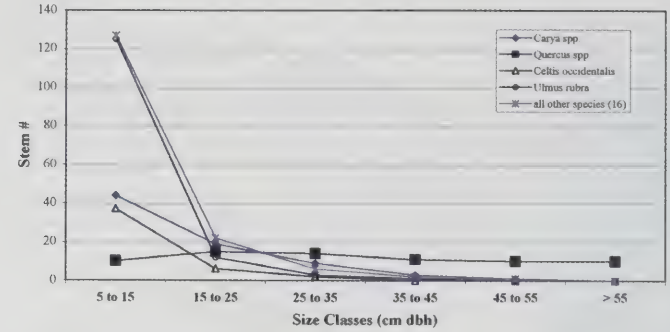


Figure 4.39. Size-class distribution of trees in forest parcels at Beaver Dam State Park with no recent fire management.

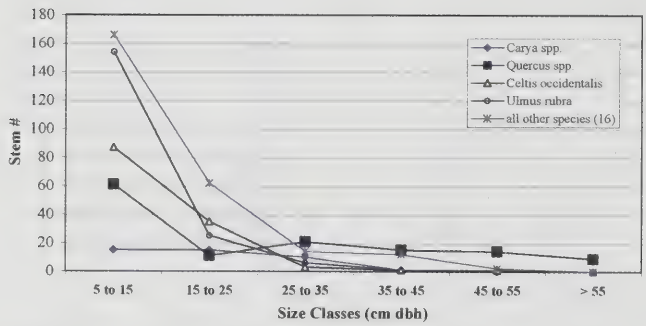


Figure 4.38. Size-class distribution of trees in Beaver Dam State Park. Data from parcels recently burned, or in one case, relatively recently released from grazing.

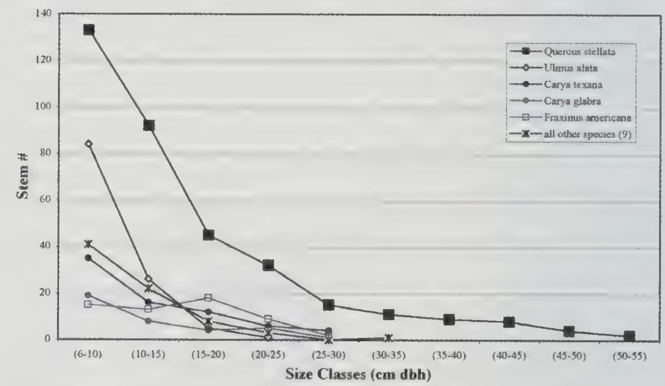


Figure 4.40. Distribution of size-classes in a dry sandstone barrens in Pope County, Illinois. Source: (163).

number of forested natural areas with 10 each followed by Washington County with a total of eight. Adams County has the most extensive acreage of high-quality forest, with a total of 4,950 acres of floodplain forest at a single site on an island in the Mississippi River. St. Clair County ranks second in acreage with 1,484 acres of high-quality forests distributed among the 10 sites. The integrity of many of these forests is threatened by invasion of exotic plant species (see Chapter 12) and excessive deer browse.

Forest Reserves—The INAI provides a focused framework for forest conservation. Not all sites qualifying for the INAI are protected in forest reserves, and not all forest reserves meet the criteria for INAI natural areas; however, it is a goal to provide protection in some form for forest communities that retain high ecological integrity and the Illinois Nature Preserves Commission has protection tools that can assist private landowners in meeting this goal. As previously noted, the majority of forest acreage in Illinois is private and classified as commercial forest (133). Forest lands in some type of reserve status have increased from 109,900 acres of "non-commercial" forest in 1962 to 244,200 in 1998 (132, 151) and the proportion of total "reserved timberland" has increased during this period from 2.8% to 5.6% of total forest acreage (Fig. 4.41). These reserved forest lands include state parks, county forest preserves, nature preserves, and other lands excluded from commercial forestry (132). For area of forest designated primarily for conservation of biodiversity, this 5.6% of protected forest lands in Illinois falls well below the 11.2% global average, or 11.8% average throughout North America (152).

PART II—NATURAL COMMUNITIES, SPECIES COMPOSITION, AND DIVERSITY

Illinois is positioned in the prairie-deciduous forest ecotone of the Midwest with forests classified as belonging primarily to the oak-hickory forest type, based on a broad classification of forests throughout the eastern United States (153). Two other major forest types are present at the state's margins. A region classified as having the maple-basswood forest type occurs in the far northwest while western mixed mesophytic forest occurs in the far southeast. These forest regions are based on the predominant tree species; other forest types occur locally within these regions depending on soil types and moisture relations. For example within the oak-hickory region, it is common for oak-hickory species to dominant slopes and ridges while maple-basswood may occur in protected ravines and along streams (140, 166).

The natural community classification system established as a framework for the Illinois Natural Areas Inventory identified four forest subclasses: *Upland forest, Sand forest, Floodplain forest*, and *Flatwoods* (67). Each is classified further into natural communities based, with the exception of *Flatwoods*, on soil moisture factors.

Floodplain forests (Fig. 4.42A) are found along riparian corridors and are differentiated into wet, wet-mesic, and mesic communities depending on flooding frequency and duration. For *Upland forest*, five community types have been recognized (Fig. 4.42 B–F): wet-mesic upland forest (typically associated with seeps or poorly drained upland swales), mesic upland forest, dry-mesic upland forest, dry upland forest, and xeric upland forest. Of *Sand forests*, only dry, dry-mesic and mesic soil-moisture classes are recognized and these are found in the major sand regions in Illinois. *Flatwoods* are distinguished regionally with northern flatwoods, sand flatwoods (only found locally on lake plains in northeast Illinois), and southern flatwoods found south of the Wisconsinan glacial boundary (see sidebar on Southern Flatwoods). Additional classification may be warranted to recognize flatwoods on the coastal plain and to differentiate differences in available soil moisture among southern flatwoods (154).

Southern Flatwoods—Southern flatwoods (Fig. 4.43) is a type of oak woodland found locally in the lower Midwest that typically is strongly dominated by Post Oak and thus often called Post Oak flatwoods. These woodlands were predominant in the Southern Till Plain Natural Division. They are characterized by a level aspect and a claypan subsoil horizon, a zone termed an argillic horizon, characterized by a sharp increase in clay content (154, 155). Because variation in composition and structure of forest stands due to steepness of slope and degree of exposure (aspect) is absent, flatwoods provide a unique insight into the role soil characteristics alone can have on tree composition, stand structure, and patterns of diversity. The claypan limits water movement (permeability) leading to seasonally moist or saturated surface soils with a perched water table during spring months, and extremely dry surface soils during the summer months from evapotranspiration. The depth to the claypan varies from about one to two feet (30–60 cm). On sites with relatively deeper soils (depth to claypan closer to two feet), White Oak can be a co-dominant species with Post Oak. With decreasing depth to the claypan, Post Oak increases in dominance. Where depth to the claypan is shallow (e.g., one foot) and/or where sand content in surface soils increases, Black-jack Oak (*Quercus marilandica*), a species known for its tolerance of droughty and low-nutrient conditions (156), becomes more common. As depth to the claypan and available water-holding capacity of the soil increases, so does tree density (Figs. 4.44, 4.45). Highlighting the influence of overstory tree density (and thus shade) on herbaceous species diversity, as tree density increases, ground cover species richness declines (Fig. 4.46). Flatwoods occurred within a mosaic of prairie and forest, and fire is assumed to have been a factor in maintaining oak dominance. Closed stands tend to have very little or no oak regeneration (Fig. 4.47). In contrast, stands that remain open despite long fire-free intervals, a result of particularly severe environmental conditions (i.e., high sand content in surface soils and shallow depth to claypan), have regeneration that suggests stable replacement (Fig. 4.48). So there is an interaction among soils, trees, and ground cover diversity. Sites with the greatest capacity to store available soil moisture are most prone to compositional and structural instability during long periods of fire absence. In sharp contrast to shaded and unburned stands, a site with a recent history including 20 years of nearly annual fire (Fig. 4.49) was found to have ground-cover diversity more than four times greater than the average for all other stands studied (92).

Species Diversity

While forest habitats occupy only 12.7% of the area of the state, they provide habitat for well over half of the native flora, highlighting the critical role forests play in the maintenance of biodiversity in Illinois. Approximately 1,414 native taxa are found in forest habitats in Illinois, about 61% of the statewide total, and the majority are herbaceous species. Forests provide habitat for a great proportion of the state's rare taxa, as well. Of the 339 species of vascular plants currently listed by the Illinois Endangered Species Protection Board as threatened or endangered in Illinois, about 50% are associated with forest habitats (157).

There are about 508 taxa of woody plants (i.e., trees, shrubs, and woody vines) found in Illinois, depending on how many subspecific taxa are recognized (e.g., varieties, subspecies), representing about 16% of the total Illinois flora including native and non-native taxa. Of all woody taxa, 370 are native and 138 (27%) are non-native. About 69% of these woody species are associated with forest habitats. The most diverse counties for tree species are in the far south. Jackson and Pope counties, each with 123 documented native tree species, have the greatest total. However, on a per-acre basis, little Hardin County (115,994 acres) has the highest tree diversity among Illinois counties with 92 native species (Fig. 4.f25). Hardin County is the southeasternmost county and typically this region has among the greatest annual rainfall statewide (see Fig. 2.8). In fact, the remaining top five ranking counties in terms of density of native tree species are Pulaski, Wabash, Massac, and Alexander, all in far southern and southeastern Illinois (Fig. 4.50). Density of non-native tree species shows a concentration in the far south, along the Wabash and Illinois rivers, and in the highly urbanized northeastern counties where DuPage County has the highest density of non-native species statewide (Fig. 4.51).

Most woody species found in Illinois are classified as shrubs (284) followed by tree species (n=261), and woody

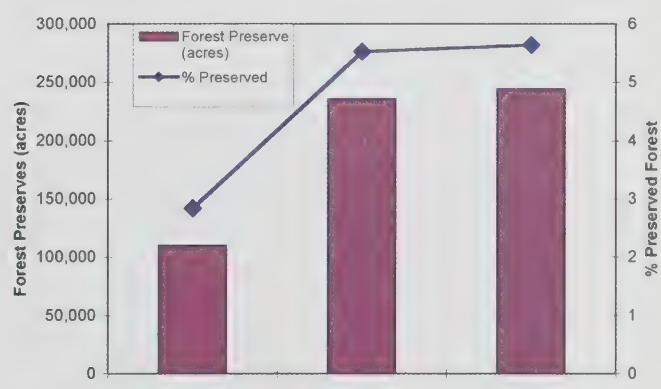
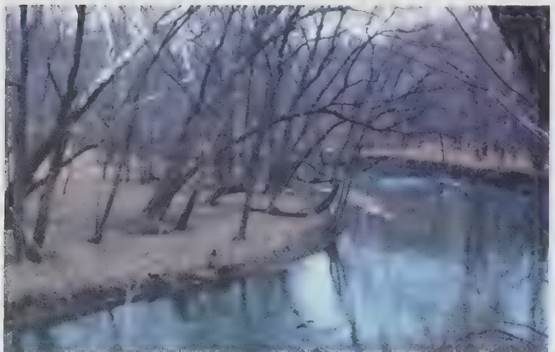


Figure 4.41. Preserved forest lands in Illinois including timberland unavailable for forest utilzation through statute or regulation (e.g., nature preserves, State parks, county forest preserves, and other protected or regulated areas). In 1962, these were referred to as "noncommercial" forests. Data sources: (131, 132, 151).


A. Floodplain forest along the Sangamon River.


B. Wet-mesic upland forest, Vermilion County, Illinois.


C. Mesic upland forest, Vermilion County, Illinois.


D. Dry-mesic forest with recent fire history, Beaver Dam State Park.


E. Dry upland forest, Pope County, Illinois.

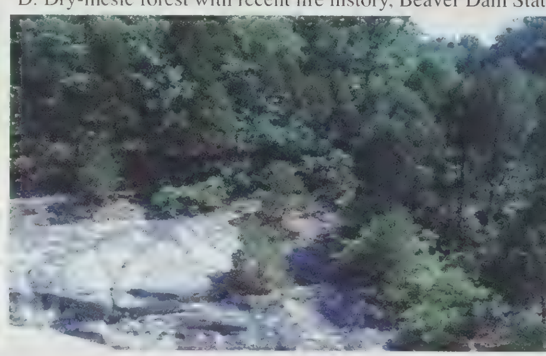

F. Xeric upland forest, Pope County, Illinois.

Figure 4.42 A–F. Representative forest habitat types in Illinois. Photos by J. Taft.


Figure 4.43. Old growth southern flatwoods community in Washington County, Illinois. Photo by J. Taft.

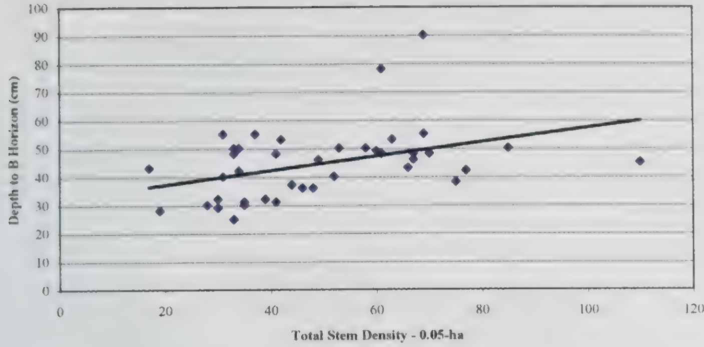


Figure 4.44. Influence of soil depth to woody stem density in flatwoods in the Southern Till Plain Natural Division. The positive correlation is statistically significant ($p < 0.05$). Depth to B is depth to claypan subsoil horizon. Source: (154).

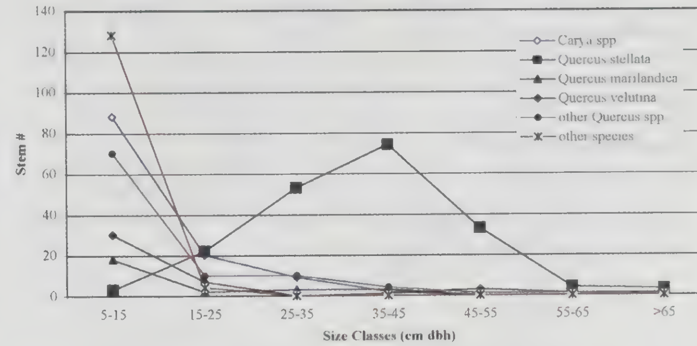


Figure 4.47. Typical size-class distribution of trees in flatwoods of the Southern Till Plain Natural Division.

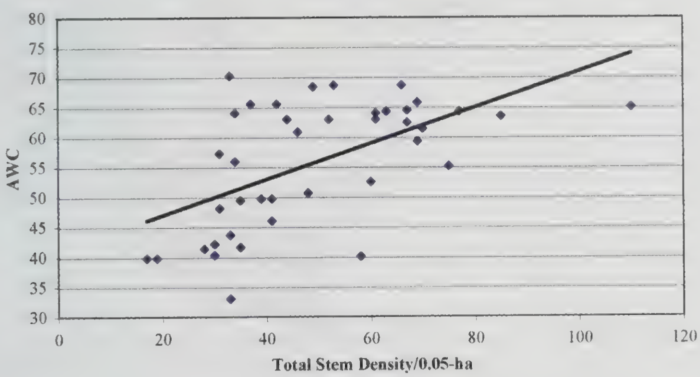


Figure 4.45. Relationship between woody stem density and soil available water-holding capacity (AWC) in flatwoods of the Southern Till Plain Natural Division ($p < 0.0005$). AWC integrates soil depth (depth to claypan) and soil texture. Source: (154).

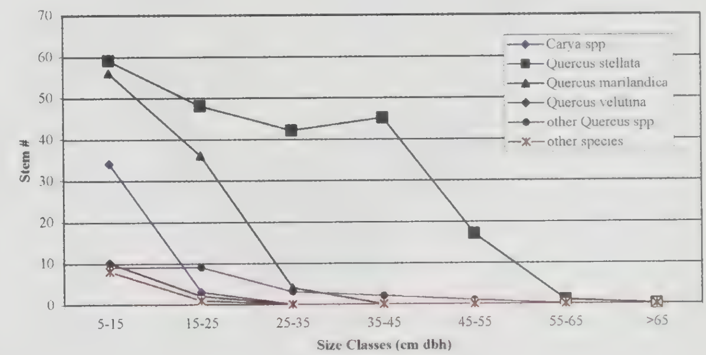


Figure 4.48. Size-class distribution patterns of trees in flatwoods growing on former lake plain in Kaskaskia River corridor in Washington County, Illinois where surface soils are high in sand content and, thus, have low available water-holding capacity.

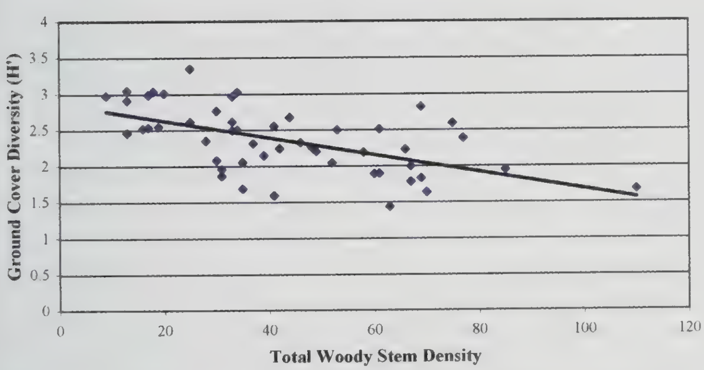


Figure 4.46. Relationship between woody stem density and ground-cover diversity (Shannon Index H') in flatwoods of the Southern Till Plain Natural Division in Illinois ($p < 0.0001$). Source: (154).

Figure 4.49. Lake Sara Flatwoods (top) in Effingham County following a 20-year period of annual burns. Contrast with this flatwoods with a site on the same soil type (bottom) lacking recent fire near Mt. Vernon in Jefferson County. While tree densities (stems > 5 cm dbh) differ greatly (284 vs. 465), basal area estimates are similar (20.2 vs. 24.7 m^2/ha) and differ largely due to different fire histories. Photos by J. Taft.

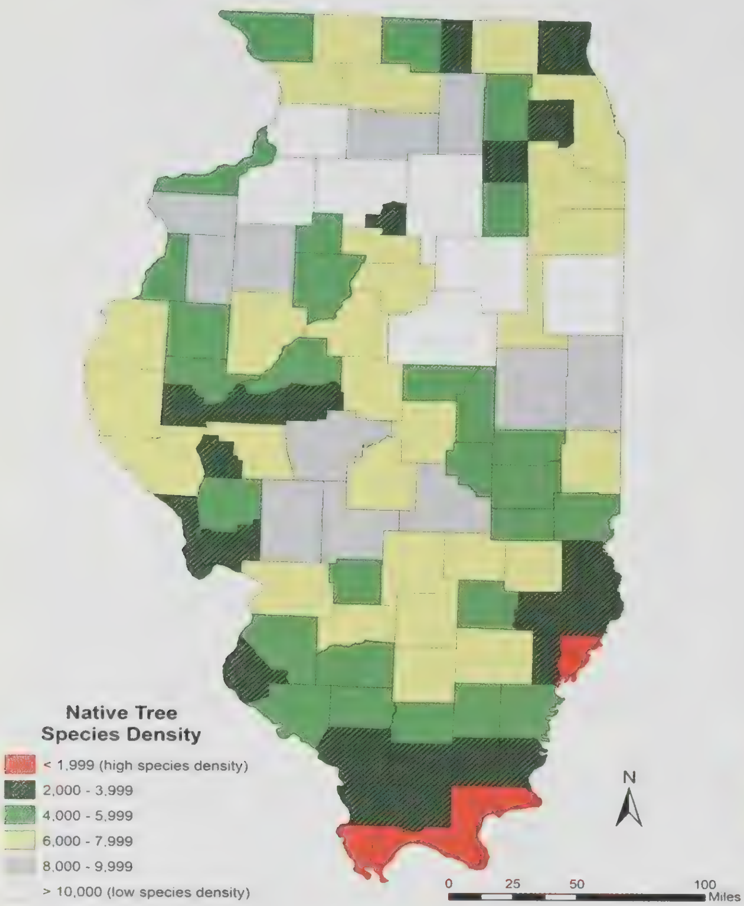


Figure 4.50. Density of native tree species on a per area basis (county area divided by number of tree species). The lower the number (darker shades), the greater the density of tree species.

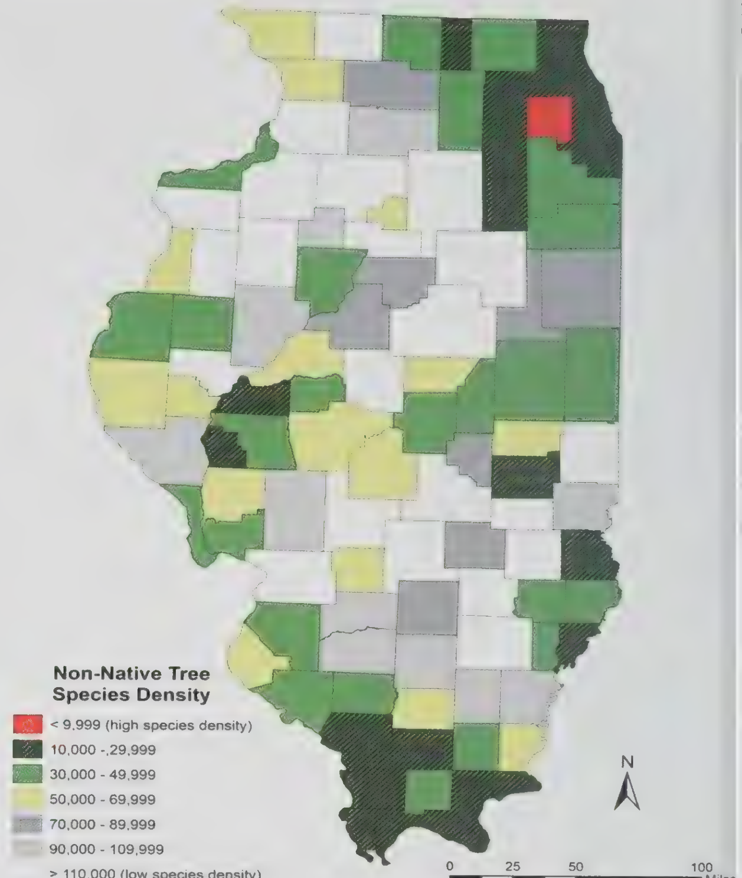


Figure 4.51. Density of non-native tree species on a per area basis (county area divided by number of tree species). The lower the number (darker shades), the greater the density of tree species.

vines (n=47). These totals exceed 508 taxa since many can be classified as either shrub or tree, or in some cases vine or shrub (137). Genera of trees with the most native species include oaks (*Quercus*—20 spp.), hawthorns (*Crataegus* —15 spp.), cherries and plums (*Prunus*—11 spp. [including 2 shrubs]), hickories (*Carya*—10 spp.), maples (*Acer*—8 spp.), and ashes (*Fraxinus*—6 spp.). Diverse genera of native shrubs include willows (*Salix*—15 including 1 hybrid), dogwoods (*Cornus*—11 spp., including 2 classified as trees), *blackberries (Rubus*—9 spp.), arrowwood and nannyberries (*Viburnum*—8 spp.), blueberries (*Vaccinium*—8 spp.), and roses (*Rosa*—7 spp.). Woody vine genera with the most native species are grapes (*Vitis*—6 spp.), (*Clematis*—5 spp.), and honeysuckles (*Lonicera*—4 native spp.).

Among forest trees, the great majority are broad-leaved deciduous species. There are seven native conifer trees in Illinois including four pines:

Jack Pine (*Pinus banksiana*—probably extirpated)
White Pine (*Pinus strobus*)
Red Pine (*Pinus resinosa*—native population possibly extirpated)
Short-leaf Pine (*Pinus echinata*)
Tamarack (*Larix laricina*)
Northern White Cedar (*Thuja occidentalis*)
Eastern Red Cedar (*Juniperus virginiana*).

With the exception of Eastern Red Cedar, these are all scarce and limited in distribution to marginal counties. In fact, three of the four pines are listed as endangered species in Illinois and two other conifers (Northern White Cedar and Tamarack) are listed as threatened. Some of these species are widely cultivated and in some cases (especially White Pine) distinguishing whether an occurrence is a native population or escaped from cultivation is not always readily apparent.

Non-native Species

Some of the most invasive adventive species in Illinois occur in forest habitats and these species infestations threaten the integrity of forests throughout the state (see Chapter 12). Some of these species include Common and Glossy Buckthorn (*Rhamnus cathartica* and *R. frangula*), Japanese Honeysuckle (*Lonicera japonica*), numerous shrubby honeysuckle species and their hybrids, Garlic Mustard (*Alliaria petiolata*), and Multiflora Rose (*Rosa multiflora*) (158). Conditions that promote the infestation and spread of exotics in forests include habitat fragmentation, altered natural disturbance cycles, burgeoning populations of White-Tailed Deer, and even invasion of exotic earthworms that promote rapid decomposition of leaf litter (159). Many of these exotic species germinate best on bare mineral soil; conditions that promote exposure of bare soil, including increased shading, can enhance habitat suitability for these species.

FOREST HEALTH

Forest health is affected negatively by certain insects, tree diseases, and weather extremes such as severe drought and prolonged flooding. Currently, the greatest insect infestation threats involve three exotic pests: the Asian Longhorn Beetle, Gypsy Moth, and Emerald Ash Borer (133). Asian Long-horned Beetles were first discovered in Illinois in the Chicago area during 1998. Favored host tree species include maples (native and non-native), Horsechestnut, and willows. Vigilant eradication efforts including quarantined infection zones appear for now to have reduced the pest. Gypsy moths, whose larvae are capable of defoliating a forest, were introduced from Eurasia to North America in 1869 and have had a devastating effect on eastern forests, but have yet to have major impacts in Illinois where they have been found in the northeastern counties. Traps placed throughout central and southern Illinois in 2005 captured only eight individuals, all in different counties (133). Attempts to slow the spread from the northeastern counties apparently have been successful. The Emerald Ash Borer, a beetle whose infestations of ash trees typically results in tree death, was discovered in southeastern Michigan in 2002 and spread to Illinois presumably in fire wood. It now threatens the ashes throughout the state.

Oak wilt is a fungal disease of oaks that disrupts translocation of water to leaves and can be fatal. It can be transferred by sap-feeding beetles, which are attracted to tree wounds, including recently pruned branches (133). Tree pruning should not occur during the April through July period to limit cross infections (160). Oak wilt can weaken trees, especially in the red oak group, making them susceptible to other diseases such as Hypoxylon canker (141). Dutch elm disease, a fungal disease introduced from Europe, has been established in Illinois for over 50 years and has had an impact on the abundance of elms throughout the state. Mortality continues although persistence of elms throughout Illinois, including American Elms, suggests some trees are less susceptible than others. Root graphs are a means of transfer enabling the disease to spread quickly through elm-dominated areas.

SUMMARY

There is great diversity of natural habitats in Illinois, with surface geology, landscape features, glacial history, fire history, and human land uses, particularly since European-American settlement, having major influences. Vegetation trends since settlement show tremendous habitat losses for all major terrestrial communities (prairie, savanna, open woodlands, and forest). Prairies persist as numerous small and isolated remnants throughout much of the state. Savannas, like prairies, reduced in extent, are now limited mostly to areas with nutrient poor soils of little agricultural value. Forests, following a period in the late 1800s of unsustainable harvests, are recovering somewhat in total area to where about a third of the original forest cover remains. However, very little original forest remains and most forests today have undergone changes in structure and composition from the original forests. Oak regeneration, in particular, is limited, suggesting a trend towards dominance by other species such as elms and maples. Invasive species including many that are non-native are an increasing threat to the long-term sustainability and integrity of Illinois ecosystems. Nevertheless, high levels of diversity remain in many plant communities and opportunities remain to conserve much of this diversity. However, insufficient resources for habitat management, including applications of prescribed fire in prairies, savanna, and woodlands, may lead to additional loss of many habitats and an overall decline in diversity.

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CHAPTER 5

Wetland Vegetation—Trends and Habitat Characteristics

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OBJECTIVES

What defines a wetland and how have wetlands changed in Illinois? What are the ecological and taxonomic characteristics of wetland plants? This chapter reviews wetlands ecology and trends since European-American settlement.

INTRODUCTION

Wetlands in North America have undergone a dramatic reduction in extent since European colonization, and wetland losses in Illinois have exceeded national trends. This chapter outlines how wetlands are defined, how they have changed in aerial extent since European settlement, and some of the factors involved in these changes, including what remains following habitat destruction, how wetlands have been classified, and some characteristics of wetland plants. Wetland restoration, mitigation, and legislation are covered in Chapter 17.

WETLANDS DEFINED

Wetlands are transitional lands between terrestrial and aquatic ecosystems that are covered by shallow water or where the water table is near or at the surface during a portion of the year (1). Saturation is the dominant factor that defines soil development and the types of plant communities present. Consequently, for regulatory purposes (see Chapter 17), wetlands are defined as those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support (and that under normal circumstances do support) a prevalence of vegetation typically adapted for life in saturated soil conditions (2). Important variables in characterizing wetlands are hydrology, the presence of hydric soils, and predominance of hydrophytic plants. These terms are discussed next.

Hydrology refers to the way water is distributed on or below the land surface. The two main sources of water are surface water from precipitation (e.g., rain, snow, and surface runoff, including flood waters) and ground water (water issuing from storage below the land surface [e.g., artesian springs and seeps]). Many wetlands in Illinois receive water from both sources although one may dominate. The length of time and total depth that an area remains saturated is referred to as the hydroperiod and depends on landscape and slope characteristics, soil permeability and drainage properties, frequency and degree of flooding and other inputs from surface water, and climate. Forces of evaporation and transpiration, (the movement of water through plants and into the atmosphere) termed evapotranspiration, are much greater during the summer months than winter months; consequently, soils can be saturated for greater periods during the dormant season despite overall lower rates of precipitation. Wetland vegetation types are shaped to a large degree by hydroperiod (see section on wetland classification below).

Hydric soils are produced under oxygen reduced (anaerobic) conditions due to saturation. They retain many diagnostic properties such as a gray coloration resulting from low available oxygen. There is a national listing of all hydric soils developed by the National Wetlands Inventory (NWI) and the Soil Conservation Service (3, 4) used as a guide for wetland mapping. Hydric soils can be mineral, organic (including peat and muck), or some combination of these. The physical properties of hydric soils remain even after the land has been drained (3).

Hydrophytic or wetland plants are species that demonstrate tolerance of saturated soils or growth in water and are classified according to the National List of Plant Species that Occur in Wetlands (5). These species were determined from a nationwide survey of botanists and ecologists and reflect the degree of certainty that a given species will be found in a wetland.

WETLAND FUNCTIONS

Like all natural habitats, wetlands have aesthetic values

that merit protection. However, wetlands also provide key irreplaceable ecological services (i.e., ecosystem functions). These sponges in the landscape contribute to the maintenance of water quality, flood control, and provide habitat for a myriad of plant and animal species. When these ecological services fail, wetlands are like the canary in the mineshaft signaling that degradation and loss of wetland habitats have exceeded the tolerance levels of the landscape to compensate for events such as severe storms and flooding. A list of ecological services is shown in Table 5.1.

WETLAND TRENDS AND HABITAT CLASSIFICATION

WETLAND TRENDS FROM THE TIME OF EUROPEAN SETTLEMENT

Wetland drainage began with the first permanent settlements of colonial America. For over 300 years the prevailing attitude was that wetlands were wastelands that presented obstacles to development and travel, and that they should be drained or filled and the land reclaimed for other uses. In the 1600s and 1700s wetlands were drained by small, hand-dug ditches. At that time it is estimated that there were 221 million acres of wetland in what would become the lower 48 states (6).

An estimate of extent and distribution of presettlement wetlands in Illinois can be derived from hydric soil map units (4), percentage of the map unit that is hydric, and map unit acreage (7). Based on these data, approximately 8,657,505 acres of Illinois (24% of the land surface) supported wetlands at the time of Euro-American settlement (circa 1820). The greatest concentration was in the east–central, central, and far southwestern counties, while the lowest concentration occurred in the northwestern and some far southern counties (Fig. 5.1). This pattern reflects the predominance of wet prairie and marsh in east-central counties and extensive bottomland forests and swamps in far southwestern Illinois (8).

With the advent of the steam-powered dredge in the 1800s, the rate of wetland loss increased. In an effort to shift responsibility for drainage and flood control from the federal government to the states, Congress passed the first

Table 5.1. Important functions and ecological services of wetlands (modified from Havera et al. [26]).

Function	Description
Erosion control	Wetlands act as reservoirs, slowing water runoff rates and thereby decreasing erosion.
Flood storage	Inland wetlands store flood waters and slowly deliver water to downstream areas. Flood plain wetlands act on riverine systems by lessening flood peaks.
Sediment control	Vegetation in floodplain wetlands reduces flood velocity, causing sedimentation of particles in flood waters.
Pollution control	Wetlands act as nutrient sinks and settling ponds by removing excess nutrients, chemicals, and particulate matter from runoff and flood waters. Wetland vegetation utilizes excess nutrients for plant growth, and chemicals become entrapped and break down in sediment.
Aquifer recharge	Some wetlands store and then slowly release water, recharging groundwater deposits.
Habitat	Wetlands provide food, cover, and nesting habitat for a wide array of fish and wildlife species while harboring a rich diversity of plant species.
Education and Research	Wetlands provide opportunity for environmental education and scientific research.
Food production	The highly productive nature of wetlands makes them a vital resource of wildlife food production.
Timber production	Forested wetlands under proper management are an important source of lumber.
Economic	Wetlands have been valued as high as $60,000 per acre ($24,000 per ha) on multiple-use basis.
Aesthetic	Wetlands, particularly undegraded examples, are aesthetically pleasing and offer seclusion and tranquility. Wetlands provide an opportunity to observe and photograph wildlife and plant species.

Swamp Lands Act in 1849, which granted all swamp and overflow land in Louisiana to the state for reclamation. By 1860, the act was extended to 14 additional states. In all, nearly 65 million acres of wetland were ceded to the states for reclamation; 1.46 million acres of wetland were ceded to the state of Illinois. From the time of Euro-American settlement until quite recently, the major cause of wetland loss in the United States has been agricultural development. In 1879, Illinois passed the Illinois Drainage Levee Act and the Farm Drainage Act, which allowed counties to organize into drainage districts to consolidate financial resources and coordinate efforts to drain wetlands (see SIDEBAR – Agricultural Drainage). Expansion of steam power accelerated the manufacture of clay drain tiles; so by the 1880s, tens of thousands of miles of tile drains were in operation on farmland in Illinois, Indiana, and Ohio.

In the first half of the twentieth century, increased mechanization further accelerated the rate of wetland loss. Mechanized farm tractors could be used more effectively than draft animals for drainage operations and mass-produced plastic drain tile resulted in drainage of much more area per day. In the Midwest, use of tractors, mechanized ditching, and reels of plastic tiles contributed to the loss of millions of acres of small marshes. As a result, by the 1970s 30% of Illinois (9.8 million acres) had been drained. Some of the world's richest, most productive farmland is in the former wetlands of Illinois (6, 9).

By the end of the 1970s, public opinion and government policy had begun to change. Scientific study had shown that wetlands provide a number of valuable functions for society. Federal and state wetland protection legislation beginning in the 1970s and 1980s has markedly decreased the rate of loss. In addition, there has been a major shift in the cause of wetland loss in the United States. From the mid-1950s to the mid-1970s, wetland losses averaged 458,000 acres per year in the lower 48 states, and agriculture was responsible for 80% of these losses. However, from the mid-1970s to the mid-1980s, net losses decreased to 290,000 acres per year, and then to 59,000 acres per year from the mid-1980s to the mid-1990s. During this latter period, development was responsible for 51% of wetland loss while agriculture caused 26%. From 1998 to 2004, development was responsible for 61% of wetland losses while, for the first time, restoration and conservation programs resulted in net gain of wetlands on agricultural land of 12,000 acres per year (10, 11, 12).

During 1998 to 2004, for the first time, there was an overall net gain in wetland acres per year. However, this gain was primarily due to the creation of open water ponds which are not an equivalent replacement (they seldom become vegetated). Although vegetated wetlands did decrease during this period, the rate of vegetated wetland loss was considerably less than in the previous study period and has steadily decreased since the 1970s (12).

Nationally, 51% of presettlement wetland acreage no longer is wetland. However, 6 of the lower 48 states, including Illinois, have lost 85% or more of their wetland area (6). Of the remaining freshwater wetland area in the lower 48 states, 51% is forested (12).

Currently in Illinois, agriculture is still the predominant land use throughout much of the state. Agricultural impacts on wetlands remain great and are exemplified by those exhibited in a recent study (13) of the agriculturally dominated Upper Sangamon River watershed in central Illinois (see SIDEBAR - Regional Wetland Status and Loss).

The most recent inventory of Illinois wetlands available, based on 1982–1985 aerial photography, shows approximately 1,026,391 acres (415,543 ha) of wetland remaining (14), excluding non-qualifying open-water habitats. Using an estimate of 8.7 million acres (3.5 million ha) of presettlement wetlands, Illinois has lost 88.1% of its wetlands since European settlement. From 24% of the land surface, wetland coverage in Illinois has been reduced to about 2.85%. Most of this remaining wetland (74%) is bottomland forest followed by shallow marsh/wet meadow (Fig. 5.4). Wetland losses are particularly dramatic in east-central Illinois (Fig. 5.5) where draining and tiling of wet prairie and marsh habitats have been extensive for agricultural development. Relatively lower rates of loss have occurred in portions of far southern Illinois, several southwestern counties, and Lake County in far northeastern Illinois.

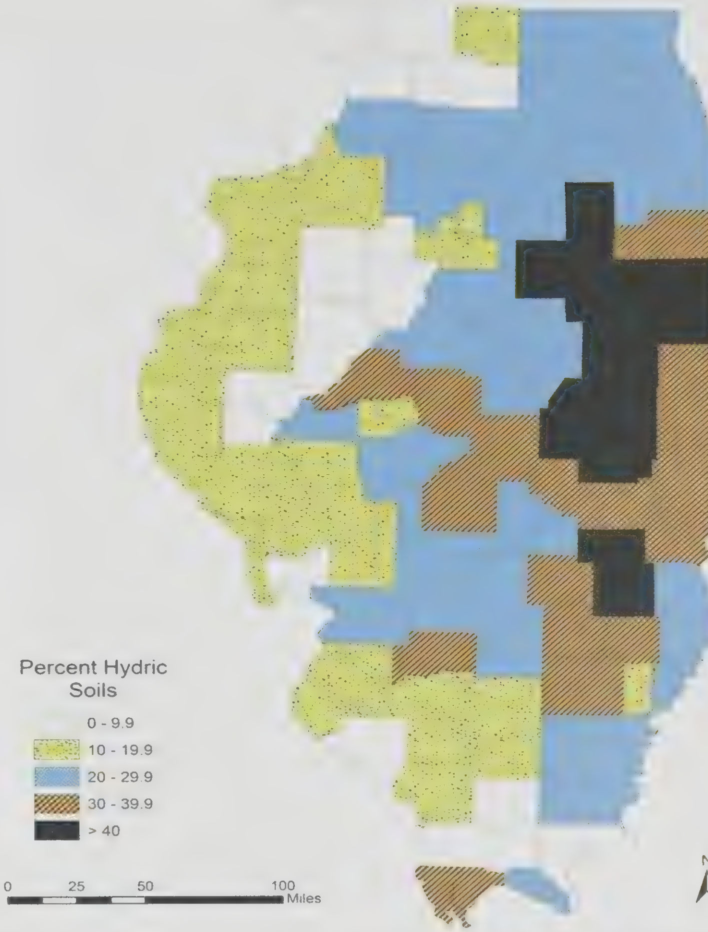

Figure 5.1. Percent hydric soils in Illinois counties (based on data from Soil Survey Staff, USDA NRCS http://websoilsurvey.nrcs.usda.gov/app/). These data reflect distribution and abundance of presettlement wetlands.

Agricultural Drainage by Clark Bullard.
There are about 87,000 miles of rivers and streams in Illinois. Drainage laws passed in 1879 promoted technologies that effectively drained wetlands by straightening streams and dredging them as much as five feet below their natural depth. This was done to provide outlets for miles of perforated drainage tiles buried about four feet below the farmland and to lower the water table to facilitate grain production. Federal subsidies for the practice became available in the 1950s but were largely abandoned by 1980 after the consequent habitat destruction triggered widespread public opposition to stream channelization. Currently, more than 1,500 drainage districts in Illinois collect local taxes for clear-cutting riparian trees and dredging sediment that collects in the bottom of these channels.

In addition to facilitating drainage, these tiles accelerate movement of nitrogen fertilizers applied to cropfields to the Gulf of Mexico. As a result, nitrate-laden water, instead of seeping slowly beneath the soil surface in an anaerobic environment conducive to denitrification, rapidly drains into the nearest tile reaching the headwater stream within minutes. Dredging practices create trapezoid-shaped channels (Fig. 5.2) that are prone to stream bank failure, increasing inputs of sediment and other pollutants into the stream. Fish spawning habitat is impaired by the added sediment and is destroyed by the periodic dredging that eliminates the habitat diversity of the streambed. As a result, water levels rise and fall more quickly due to the tiles, leaving saturated stream banks prone to slumping under their own weight. Severed from their natural floodplains, the deepened channels carry greater water volume promoting more down-cutting and, consequently, more stream bank slumping. Left alone, natural forces would eventually widen the top of the channel and create a narrow meandering low-flow channel at the bottom. However, periodic maintenance projects by drainage districts at approximately 20–30 year intervals typically return the channel to the inherently unstable trapezoidal form, and the process repeats.

Recent research and demonstration projects are showing how to reconfigure these stream channels by working with the natural forces that are trying to restore altered headwater streams. The idea is to accelerate the natural process of widening the top of the channel and constructing a mini-floodplain at the bottom, with a low-flow channel meandering through it (Fig. 5.3). Soil can be placed on adjoining fields, tall grasses can shade the narrow channel to prevent algal growth, and the larger channel cross section can accommodate more diverse vegetation without impairing drainage.

Figure 5.2. Typical trapezoid-shaped dredge channel just after completion. Note the clearance of riparian vegetation. Photo by C. Bullard.

Figure 5.3. An alternative stream within a channel design for meeting field tile drainage needs. Photo by C. Bullard.

WETLAND CLASSIFICATION AND HABITAT QUALITY

Illinois, with its long north-to-south axis of nearly 400 miles is uniquely positioned geographically to include a great diversity of habitats, from cypress and tupelo swamps in far southern Illinois (Fig. 5.6) to tamarack bogs (see SIDEBAR - Peatlands) in the far north (Fig. 5.7). The latter, because they were among the first lands in the upper Midwest released from late Pleistocene glaciation, are among the oldest bogs of glaciated regions and all but one in Illinois have undergone lake fill and are fully vegetated (e.g., Fig. 5.8). As previously noted (Chapter 3), pollen content in submerged layers of these peatlands provides a stratified record of regional vegetation changes since the last ice age (15).

Illinois' original wetlands included a diverse assemblage of wetland types. Wetlands have been classified in a variety of ways depending on the objectives of the classification. The classification used for the Illinois Wetland Inventory (IWI), conducted during the 1980s and the last comprehensive survey, is based on the National Wetland Inventory (1). The Illinois Natural Areas Inventory (INAI) developed a natural community classification system (23) for the assessment of high-quality remnant natural areas, including wetlands. The following characterization of contemporary wetlands is based primarily on INAI classifications.

The INAI natural community classification system recognized seven wetland subclasses: *Marsh, Swamp, Bog, Fen, Sedge Meadow, Panne*, and *Seep and Spring*. Of the wetlands remaining in Illinois, 8,364 acres at 145 sites meet the criteria for the INAI. This total is about 0.8% of remaining acreage and 0.1% of the original amount. Of these wetlands, those in the one to five-acre size class are

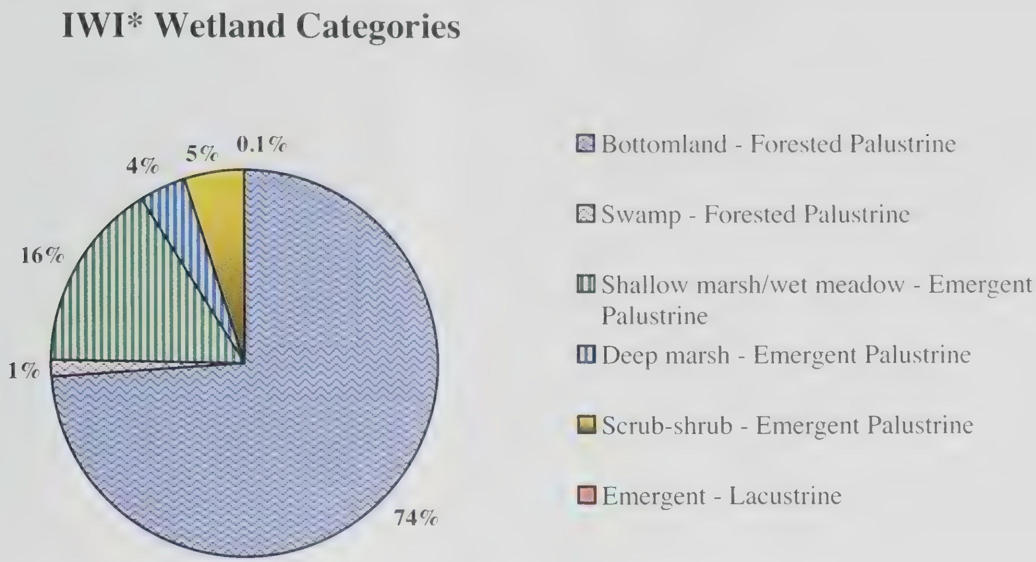

Figure 5.4. Percent of remaining wetland types in Illinois based on Illinois Wetland Inventory classifications. *modified by excluding open-water habitats.

most frequent (Fig. 5.12); however, about 72% are greater than five acres. Wetland quality appears to be somewhat area-dependent as smaller sites appear less capable of sustaining populations of remnant-dependent plant species (24). The locations of high-quality, relatively undisturbed, wetland communities identified during the INAI (25) show concentrations locally along the Fox, Des Plaines, and Kankakee rivers in northeastern Illinois, along the middle Illinois River valley, and in the Gulf Coastal Plain of far southern Illinois (26). Of these high-quality wetlands, the greatest acreage is among marsh (see SIDEBAR—Marsh), swamp, pond, shrub swamp, and sedge meadow communities. While based on the total number of sites, sedge meadows are most common followed by marsh and pond (Fig. 5.13).

In comparative studies as part of the Critical Trends Assessment Program (see introduction to CTAP in Chapter 3), high-quality marshes in Illinois (i.e., INAI Grades A or B) have been found to have greater native plant species diversity than marshes selected at random statewide and these "average" marshes have many more non-native species. Specifically, native species richness from standardized vegetation sampling in INAI marshes was over twice that found in randomly selected marshes. Furthermore, while non-native species were 5% in the high-quality marshes, non-native species comprised 41% of the composition in random marshes (27).

Floodplain forests in the INAI classification are included under the forest, rather than wetland, community type (23). A total of 9,133 acres of floodplain forest is included in the INAI. However, not all floodplain forests qualify as wetlands due mostly to failure to meet hydric soil or hydrological criteria, particularly mesic floodplain forests (205 acres). See Chapter 4 (Forest section) for further discussion of floodplain forest habitats in Illinois.

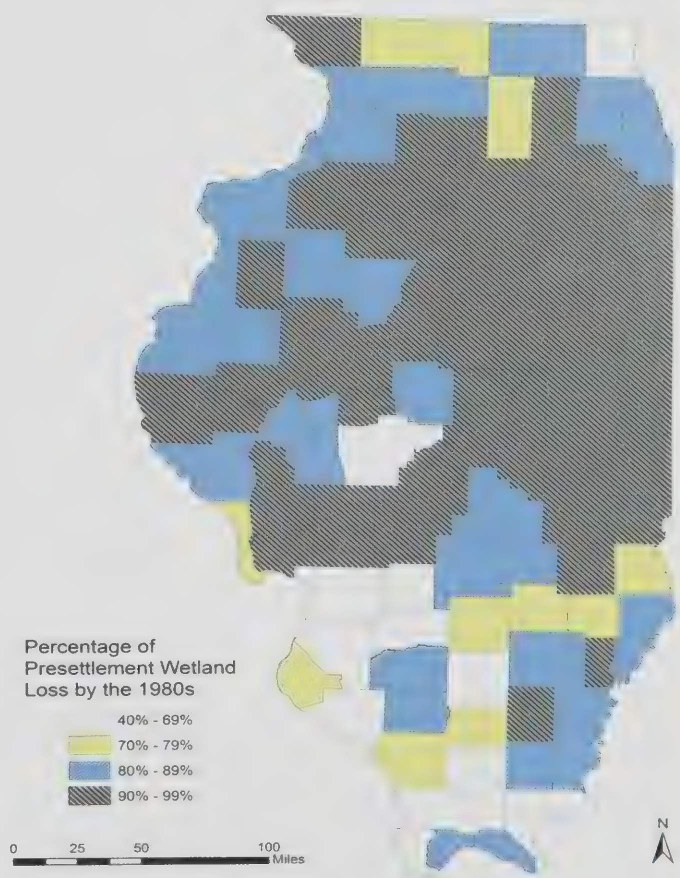

Figure 5.5. Percentage of presettlement wetlands losses in Illinios counties by the 1980s.

Regional Wetland Status and Loss by Brian Wilm. A comprehensive study of wetland habitat within the Upper Sangamon River watershed of central Illinois was conducted between 2002 and 2005 (13). Encompassing more than 1,400 square miles, the Upper Sangamon River watershed is representative of many other watersheds within Illinois as it is strongly dominated by rowcrop agriculture. Because of the large size of the watershed, 80 randomly selected sections, generally one-square mile in size, were investigated. A major study goal was to compare existing wetlands to those identified in the National Wetlands Inventory (NWI) in an attempt to not only field test the accuracy of the NWI, but to also identify any trends in wetland loss that might be apparent. Conducted in the 1980s, the NWI was a comprehensive, remote-sensing-based wetland mapping and classification scheme conducted across Illinois and the nation. Wetland data from the NWI are often referenced when discussing the status of Illinois wetlands. Wetlands in the Upper Sangamon River watershed study refer to areas that meet the technical guidelines for wetlands, as described in the Army Corps of Engineers *Wetlands Delineation Manual* (2).

The NWI mapped 371 wetland sites across the sampled area. However, investigation indicated that only 46% of these sites were actual wetlands; about 4% had been altered and were no longer wetlands while 50% had been misclassified as wetlands when in fact they were not. A large part of this inaccuracy was attributable to wetlands identified as "farmed." Sixty-nine of these farmed wetlands were identified in the NWI, however, only three of these actually were functional wetlands. The National Wetlands Inventory also failed to identify 33 other wetlands.

Inaccuracy in the NWI was not evenly spread throughout the watershed. Of the NWI wetland sites directly associated with the Sangamon River and its floodplain, most were found to meet the technical guidelines for wetlands. However, fewer of the NWI-identified wetlands associated with the major tributaries of the Sangamon River were determined to actually be wetlands. In the upper reaches of the watershed, a mere 6% of wetlands classified by NWI were found to be jurisdictional wetlands. Of the misclassifications in the upper reaches of the watershed, 70% were attributable to NWI-identified wetlands that were farmed.

From a wetland habitat standpoint, little has changed in the Upper Sangamon River watershed since the NWI was conducted. However, there is substantially less true wetland habitat than suggested by the NWI. Although many of these sites still exist, particularly forests and ponds, many are not considered wetlands by the Army Corps of Engineers regulatory program and, thus, are not afforded the protection status given wetlands. Also, recent regulatory changes have limited the protection for isolated wetlands, those typically not associated with streams and rivers, thereby making these sites more vulnerable to destruction. The large number of farmed wetlands identified in the NWI also is misleading. Although most of these sites still exist, typically occupying shallow depressions in the landscape, most are not functional wetland habitat because they have been drained and are farmed in all but the wettest years. They are mostly unvegetated, except for planted crops, and provide virtually no wildlife habitat. In general, very little functional wetland habitat occurs in this watershed outside of the Sangamon River, its major tributaries, and their associated floodplains. If this trend holds for other agriculturally-dominated watersheds across Illinois, the status of wetland habitat throughout much of Illinois appears quite dire.

Figure 5.6. Swamp with Bald Cypress (*Taxodium distichum*) in southern Illinois. Photo by J. Taft.

Figure 5.7. Bog in Lake County, Illinois showing open-water zone, floating mat, tall shrub and forested bog zone with Tamarack (*Larix laricina*). Photo by J. Taft.

Figure 5.8. Aerial photograph of Gavin Bog in Lake County, Illinois, an illustration of a bog that has undergone lake fill. Trees in middle of bog are Tamaracks (*Larix laricina*). Photo taken by M.H. Scott.

Figure 5.9. Sphagnum moss in Volo Bog, Lake County, Illinois. Photo by J. Taft.

Figure 5.10. Graminoid fens in Will and McHenry counties, Illinois. Species in photo on bottom include Ohio Goldenrod (*Solidago ohiensis*) and Marsh Blazingstar (*Liatris spicata*). Photos by M.K. Solecki.

Peatlands—Of remaining wetlands in Illinois, most occur on mineral soils or a combination of mineral soils and highly decomposed organic matter termed muck (organic silts—well decomposed and indistinguishable plant materials). However, a specialized group of wetlands known as peatlands, although never widespread in the state, were locally common in the northern counties (Table 5.2). Peatlands are wetlands with organic soils developed from partially decomposed plant material. Organic matter accumulates when plant growth exceeds decomposition. Factors that retard decomposition such as cold temperature and anaerobic (saturated) conditions contribute to peat accumulation (16); thus, peatlands in the Midwest mostly are restricted to the cooler northernmost regions. Peat in the upper Midwest is derived from three principal sources: sedges, mosses (especially *Sphagnum* spp. [Fig. 5.9]), and limnetic origins. In addition to the peat substrate, typically there is a specialized flora associated with peatlands including many rare species for Illinois occurring at the southern extent of their midwestern ranges (e.g., 17 [see section on threatened and endangered wetland plants]).

Two principal peatland types occur in Illinois: minerotrophic peatlands and oligotrophic peatlands. Peatland type is controlled by a complex of climatic, hydrological, topographic, and geological factors (16). Minerotrophic peatlands are characterized by a predominately sedge-composed peat saturated with mineral-rich, flowing alkaline or circumneutral ground water. Examples include all fens in Illinois (e.g., graminoid fen [Fig. 5.10], shrub fen, and forested fen). Oligotrophic peatlands are characterized by sedge and/or moss peat saturated with ground and rain water. However, due to limited outlet channels, the water becomes acidified from accumulation of hydrogen ions released by a developing Sphagnum mat. These are the level bogs of northeastern Illinois including graminoid bog, low-shrub bog, tall-shrub bog, and forested bog communities. Ombrotrophic peatlands (raised bogs), a third basic type, do not occur in Illinois.

Distinctions between the peatland community types of bog and fen have not always been made. Yet these wetlands support such distinctive biota that separate classification for scientific and conservation purposes is merited. All bogs in Illinois developed from fens in glacial pothole depressions (18) where hydrological outlets are limited and acids released from Sphagnum mats have affected the local soil and water chemistry (17). Fens are primarily concentrated in Illinois in the northeastern counties and locally in the central Illinois River valley where the calcareous nature of the glacial till mineralizes the groundwater with an alkaline reaction. Where groundwater meets a resistant stratum, such as bedrock (also calcareous in northeastern Illinois), it flows laterally until issuing from the margin of a pothole depression, the edge of a moraine, or locally from the sides of river valleys often as diffuse seeps and spring runs. Permanent ground-water seepage results in cold anaerobic soil conditions, incomplete decomposition, and peat accumulation.

Precisely determining the total area of original peatland (bog or fen) in Illinois is not possible due to extensive habitat destruction; however, an estimate can be made from early soil surveys. According to Soper and Osbon (19), several Illinois counties had peat deposits (Fig. 5.11). Muck and peat deposits often occur within the same wetland complex; consequently, early soil surveys included muck soils in their total estimates of peat for each county. Although these early soil surveys indicate that Lake County supported the greatest total peatland (and muck) area in the state (Table 5.2), the largest single peat deposit was in the former Cattail Slough in Whiteside County, a one-mile -wide valley extending about 12 miles with peat measured to a depth of 30 feet (19). Peat has been mined in this deposit for fuel since the 1800s (20). The area is still used for peat production and rowcrop agriculture, although some degraded wetlands persist on the margins of the valley. The Illinois Natural Areas Inventory (INAI) recognized a total of 183 acres of fen habitats at 40 sites and 232 acres of bog habitat at 11 sites for 415 total acres of high-quality peatlands in Illinois. Despite the difficulty of precisely determining the total area of original peatland in Illinois, the historic data available compared with results from the INAI reveal a clear trend of substantial loss and degradation of peatland habitats.

Factors leading to the destruction and degradation of peatlands include drainage and lowering of the water table, cultivation, grazing by domestic stock, exotic species invasion, and peat harvesting. For a time into the 1960s, Illinois ranked second among all states in total peat harvest, a surprising statistic considering several other northern states support far greater acreage of peatland. There were six major areas of peat production in Illinois during the late 1960s (Fig. 5.11). Though peat was mined historically for fuel in Illinois, in more recent years it has been harvested for horticultural purposes. As a result of oxidation, once a peatland is drained or the hydrology altered, the peat decomposes, forming muck if saturated (21) or humus if seasonally dry (22).

Table 5.2. Estimates of historical (18) and contemporary (4) acres of peat and muck in Illinois compared with the results of the Illinois Natural Areas Inventory (INAI) (25). From Havera et al. (26).

County	Historical peat and muck	soil survey data		INAI Grades A and B
		Muck	Peat	
Boone	NA[a]	3,557	0	0
Cook/DuPage	NA	10,341	0	22
DuPage	4,186	—[b]	0	0
Kane	9,299	9,639	0	23
Kankakee	1,747	1,707	0	0
Lake	24,384	17,122	465	286
Lee	NA	999	0	0
Mason	NA	1,046	0	0
McHenry	NA	20,485	1,760	226
Tazewell	1,344	790	0	0
Whiteside	2,580[c]	3,455	0	0
Will	NA	2,385	0	0
Winnebago	1,427	3,557	0	0
Woodford	NA	NA	0	5
Statewide	42,387	98,331	2,225	562

[a] Not available
[b] See Cook/DuPage
[c] Peat acres only

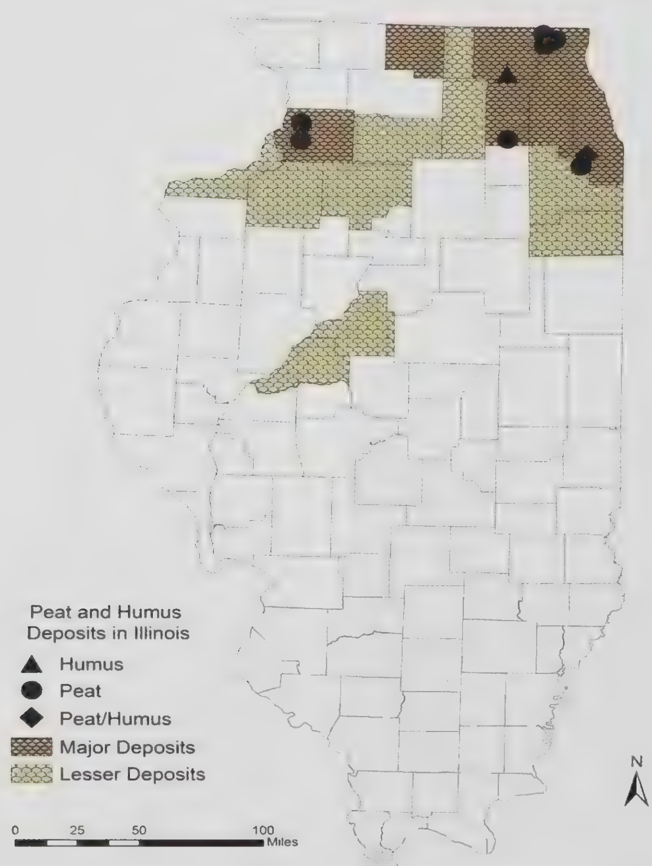

Figure 5.11. Location of peat and humus deposits in Illinois. Symbols represent locations of major peat and humus mining. Modified from (22).

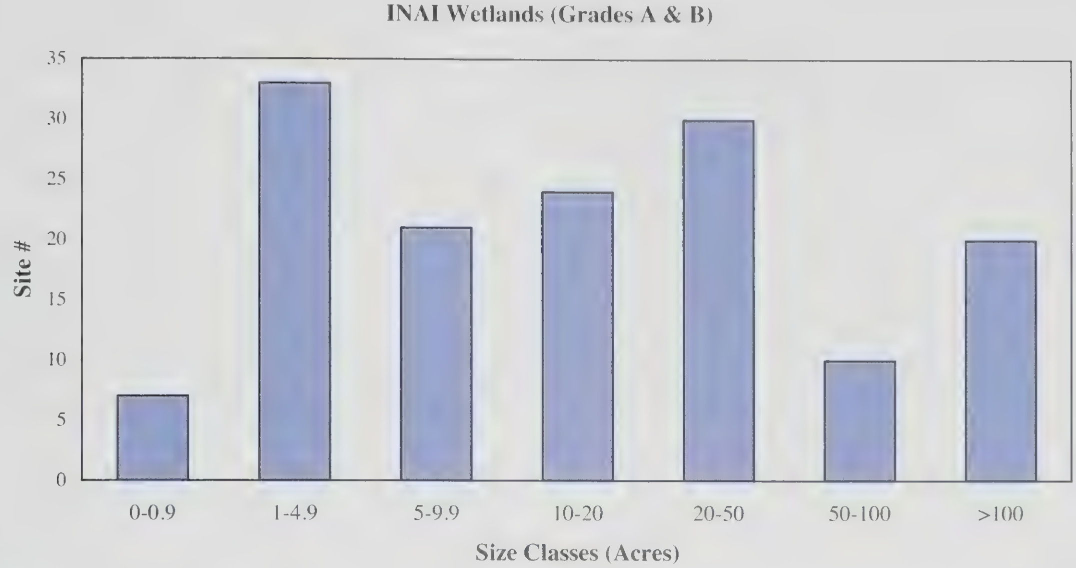

Figure 5.12. Distribution of size classes of wetlands recognized by the Illinois Natural Areas Inventory (INAI).

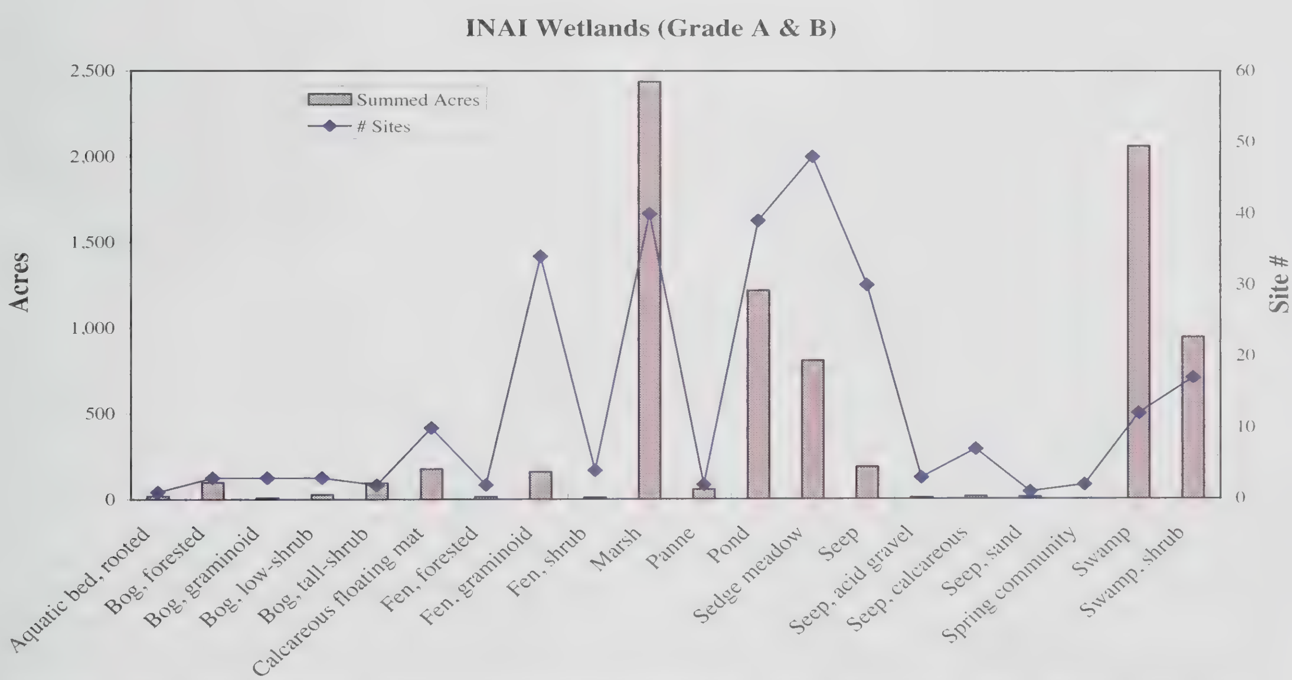

Figure 5.13. Total acreage and site number for wetland habitats recognized by the Illinois Natural Areas Inventory (INAI) as high quality (Graded as A or B).

Marsh—Marshes are palustrine wetlands characterized by having water at or near the surface during most of the growing season, dominance by herbaceous vegetation, and organic or mineral soils. Two marsh community types are recognized in Illinois (23): marsh and brackish marsh (very rare). Community structure is controlled largely by water depth and hydroperiod. Shallow-water zones are dominated by emergent, rooted herbaceous vegetation. In deeper-water zones, floating aquatics and open water become more prominent. In transitional zones, a combination of these species exists and vegetation cover is intermediate between deep and shallow-water zones. Shores of marshes often are dominated by superior competitors such as Cattails (*Typha* spp.) and Common Reed (*Phragmites australis*). Marshes often co-occur with other wetland types including sedge meadow, wet prairie, and sometimes seep, shrub swamp, and open-water pond communities. These community types often gradually merge or have variable boundaries through the growing season; consequently, distinguishing community boundaries can be somewhat arbitrary. In general, certain species signal each community type with Cordgrass (*Spartina pectinata*) suggesting wet prairie, Tussock Sedge (*Carex stricta*) suggesting sedge meadow, Marsh Marigold (*Caltha palustris*), Swamp Wood Betony (*Pedicularis lanceolata*), and sometimes the sedge *Carex sterilis* suggesting seep, Buttonbush (*Cephalanthus occidentalis*) and willows (*Salix* spp.) suggesting shrub swamp, and presence of Common Cattail (*Typha latifolia*), Rice Cut-Grass (*Leersia oryzoides*), and Common Water Plantain (*Alisma plantago-aquatica*), and low abundance or absence of signal species for other community types, indicating marsh.

WETLAND PLANTS

TAXONOMIC GROUPS, WETNESS RANKINGS, AND GROWTH FORM

About 2,959 taxa of vascular plants are known from Illinois, a listing modified from Mohlenbrock (29) not including all subspecific taxa (28). These species have been ranked according to their affiliation with upland and wetland habitats (5). Most are obligate upland species (1,287), including a major proportion of adventive taxa (Fig. 5.14). Obligate wetland species, the next largest single group, include 511 species (17%). These rankings correspond to wetness coefficients ranging from -5 for obligate wetland species to +5 for upland species (Fig. 5.14). For obligate species (OBL or UPL), there is a high degree of confidence (99% to 100%) the species occur in wetland or upland habitats. The remaining 1,161 taxa (39% of total flora) are ranked as facultative; those ranked FAC+ to FACW+ are considered wetland species. While about 54% of Illinois' wetland flora (those species ranked OBL) can, with 99% to 100% confidence, always be found in a wetland community, 46% also can be found at least occasionally in upland habitats. Combining OBL and facultative wetland species totals 862 native and 90 non-native wetland plants in the state, about 32% of the total flora (Fig. 5.15). When considering only species native to Illinois, wetland species comprise about 42% of the total flora despite occupying a mere 2.85% of the state's land area.

An estimate of diversity of wetland plant species proportionate to county size indicates that Wabash County has the highest richness followed by Massac, Pulaski, and Alexander counties, all in southern Illinois (Fig. 5.16). Cook County followed by Lake County actually have the greatest total richness of wetland species with 569 and 511 native taxa, respectively; however, on a per acreage basis, they do not rank among the most diverse.

A taxonomic assessment of the wetland vascular flora indicates that the sedge family (Cyperaceae), with 163 wetland species, has the greatest number followed by the grass family (Poaceae) with 81 species (Fig. 5.17). Other important families include the sunflower (Asteraceae), orchid (Orchidaceae), mint (Lamiaceae), and rose (Rosaceae) families. The most species-rich genus is *Carex*, with 90 wetland species. Most wetland plant species (57%) are forbs (Fig. 5.18). Sedges, important species in many wetland community types, rank as the second most important physiognomic group in the Illinois wetland flora.

THREATENED AND ENDANGERED SPECIES, EXTIRPATIONS, AND EXTINCTIONS

About 16.4% of the native vascular flora of Illinois is listed by the Endangered Species Protection Board as threatened or endangered (30). Slightly more, 17.7%, of the native wetland species are listed as threatened or endangered. The number of threatened and endangered wetland plant species with extant populations for each county shows a concentration in northeastern Illinois and secondarily in far southern Illinois (Fig. 5.19). The number of threatened and endangered wetland species extirpated from each county also shows a concentration in the heavily developed northeastern counties and locally elsewhere in Illinois (Fig. 5.20). Taken together, the patterns of occurrence for extant and extirpated threatened and endangered wetland species in Illinois show a concentration in the northeastern counties of Lake, Cook, McHenry, Kane, and Kankakee. Lake County historically supported the greatest number of wetland plant species that are listed as threatened and endangered with 85.

Habitats with the greatest number of threatened and endangered wetland species are the peatland communities of bog and fen, each with 34 listed species (Fig. 5.21). Another habitat that supports numerous rare wetland species, moist sand, is an amalgamation of several habitat types unified by similar moist, sandy substrates. These include portions of the Chicago lakeplain, margins of sand ponds, and wet to wet-mesic sand prairie. Swamps (principally in southern Illinois), floodplain forests (also mostly those in southern Illinois), seeps and springs, pannes, and marshes also support more than 10 threatened and endangered wetland plant species (Fig. 5.21).

Of the 52 or so plant species presumed to be extirpated from Illinois (modified from 31), 35 are wetland species (Table 5.3). Several additional wetland species listed as endangered (30) are not presently known from extant Illinois populations, and one Illinois endemic species, Thismia (*Thismia americana*), is probably extinct. Most, but not all, of these extirpated species were confined to wetlands in the northern, specifically the heavily urbanized northeastern, counties. This is a dramatic difference from prairie species where only five taxa are believed to be extirpated despite loss or degradation of 99.99% of prairie habitats (see Chapter 4, Prairie section). Why so many more

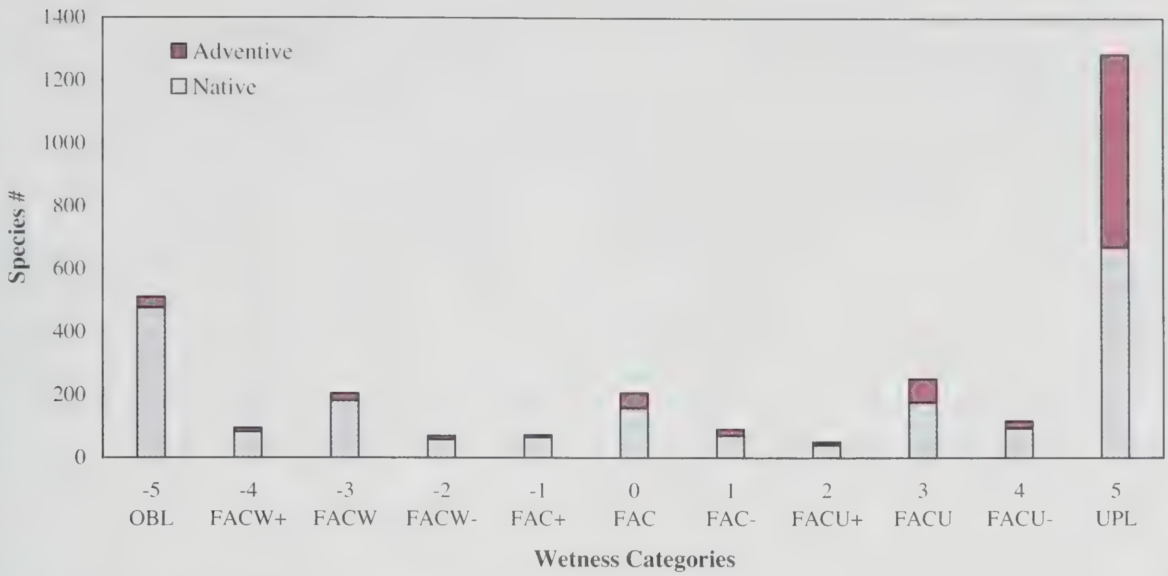

Figure 5.14. Distribution of the Illinois flora by wetness categories (5, 28).

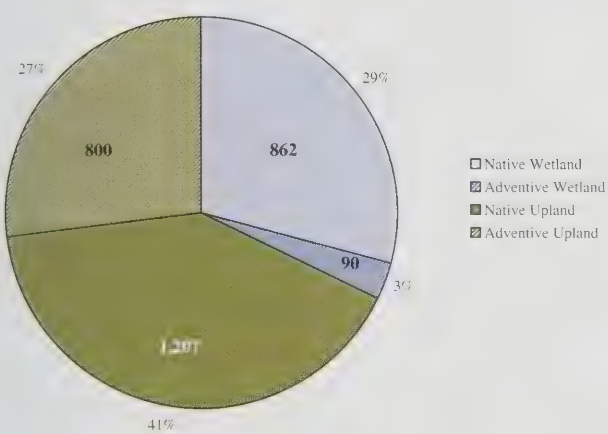

Figure 5.15. Number of vascular plants classified as wetland (FAC+ and wetter) and upland species including native and adventive taxa (from 28).

wetland species have been extirpated from Illinois compared to prairie, despite a greater proportion of wetland habitat remaining, suggests wetlands in Illinois either supported a greater number of scarce species or regions supporting rare species selectively have been destroyed. Most of the extirpated species have principal ranges north of Illinois, so habitat loss and degradation in heavily urbanized northeastern Illinois appear to be primarily responsible for these species losses.

ACKNOWLEDGMENTS

For providing updated information from the statewide natural heritage database, we thank Tara Kieninger and Jeanie Barnes of the Illinois Department of Natural Resources. Many thanks to Diane Szafoni (INHS) for her contributions in providing maps of county-level data of botanical resources.

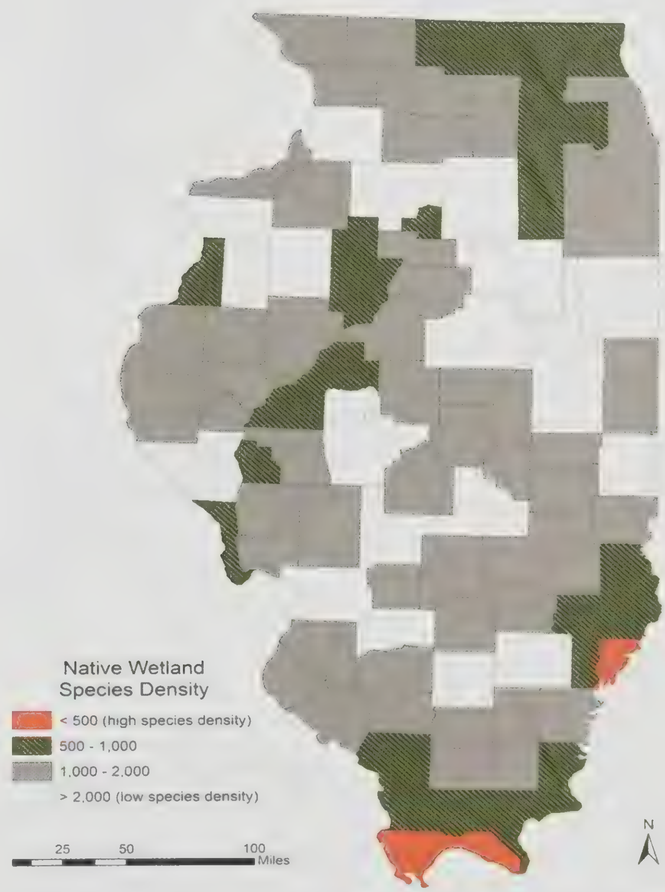

Figure 5.16. Richness of native wetland species in Illinois counties weighted by number of species per area (species density). Species density is the quotient of county area and wetland species number (smaller the number, the greater the species density).

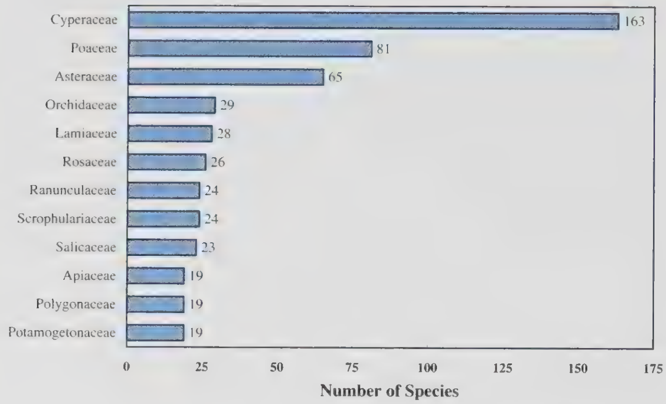

Figure 5.17. Rank order of plant families with the greatest number of wetland species in Illinois.

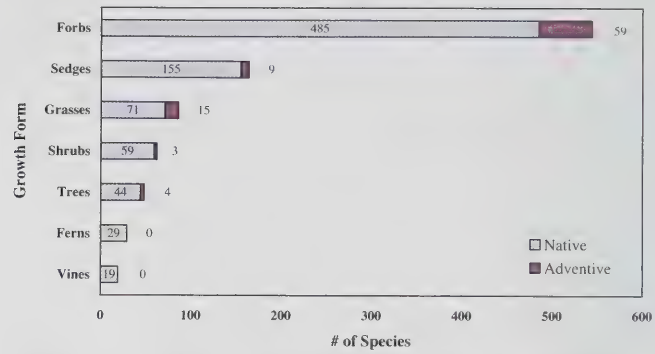

Figure 5.18. Number of native and non-native wetland species by growth form in the Illinois flora.

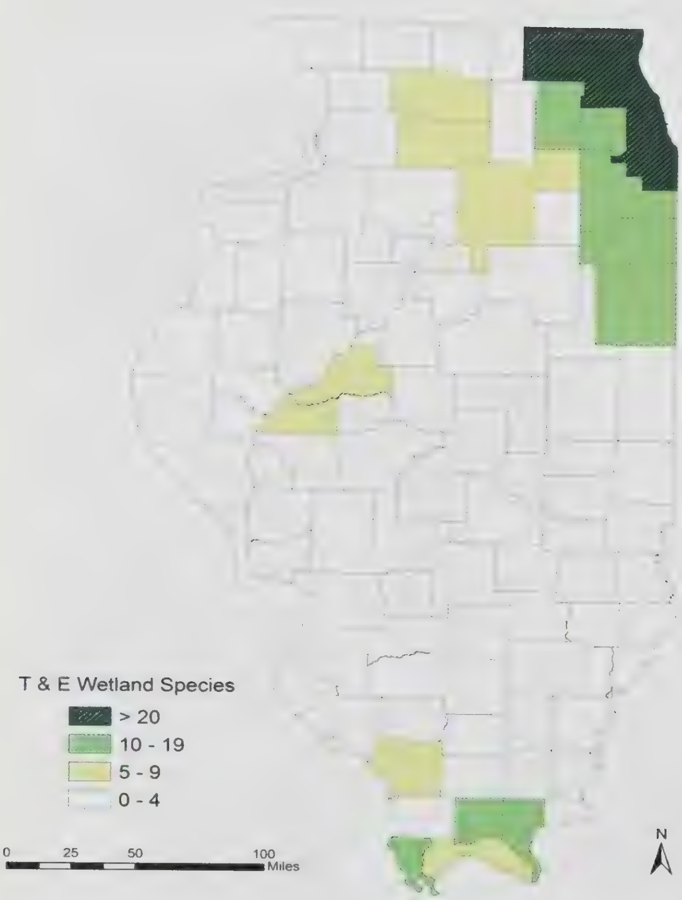

Figure 5.19. Distribution of wetland plant species listed as threatened and endangered (T & E) in Illinois (32).

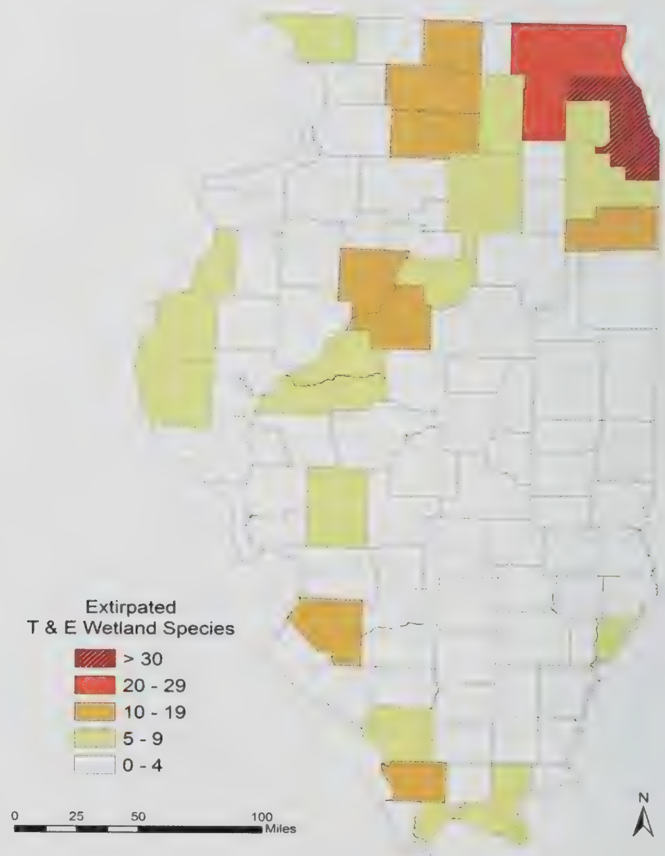

Figure 5.20. Distribution of wetland plant species listed as threatened or endangered that have been extirpated from Illinois counties (32).

Table 5.3. Wetland plant species thought to be extirpated from Illinois. This list does not include species still listed as endangered with no known extant populations in Illinois. Modified list (31).

Common name	Scientific name
Bog Rosemary	*Andromeda polifolia* var. *glaucophylla*
Dragon's Mouth Orchid	*Arethusa bulbosa*
Drooping Wood Reed	*Cinna latifolia*
Bluebead	*Clintonia borealis*
Early Coral Root	*Corallorhiza trifida*
Waterwort	*Elatine brachysperma*
Spike Rush	*Eleocharis caribaea*
Horsetail Spike Rush	*Eleocharis equisetoides*
Marsh Horsetail	*Equisetum palustre*
Brown Plume Grass	*Erianthus brevibarbis*
Umbrella Grass	*Fuirena scirpoidea*
Purple Avens	*Geum rivale*
Rattlesnake Manna Grass	*Glyceria canadensis*
Goldenpert	*Gratiola aurea*
Mare's Tail	*Hippuris vulgaris*
Engelmann's Quillwort	*Isoetes engelmannii*
St. John's Wort	*Hypericum ellipticum*
Twinflower	*Linnaea borealis*
Water Hyssop	*Mecardonia acuminata*
Mountain Holly	*Nemopanthus mucronatus*
Phlox	*Phlox carolina var. angusta*
White-fringed Orchid	*Platanthera blephariglottis*
Tall White Orchid	*Platanthera dilatata*
Hooker's Orchid	*Platanthera hookeri*
Marsh Bluegrass	*Poa paludigena*
Pondweed	*Potamogeton epihydrus*
Pondweed	*Potamogeton vaseyi*
Spearwort	*Ranunculus ambigens*
Small Yellow Water Crowfoot	*Ranunculus gmelini var. hookeri*
Bulrush	*Scirpus microcarpus*
Bulrush	*Scirpus pedicellatus*
Bulrush	*Scirpus subterminalis*
Least Burreed	*Sparganium minimum*
Virginia Chain Fern	*Woodwardia virginica*

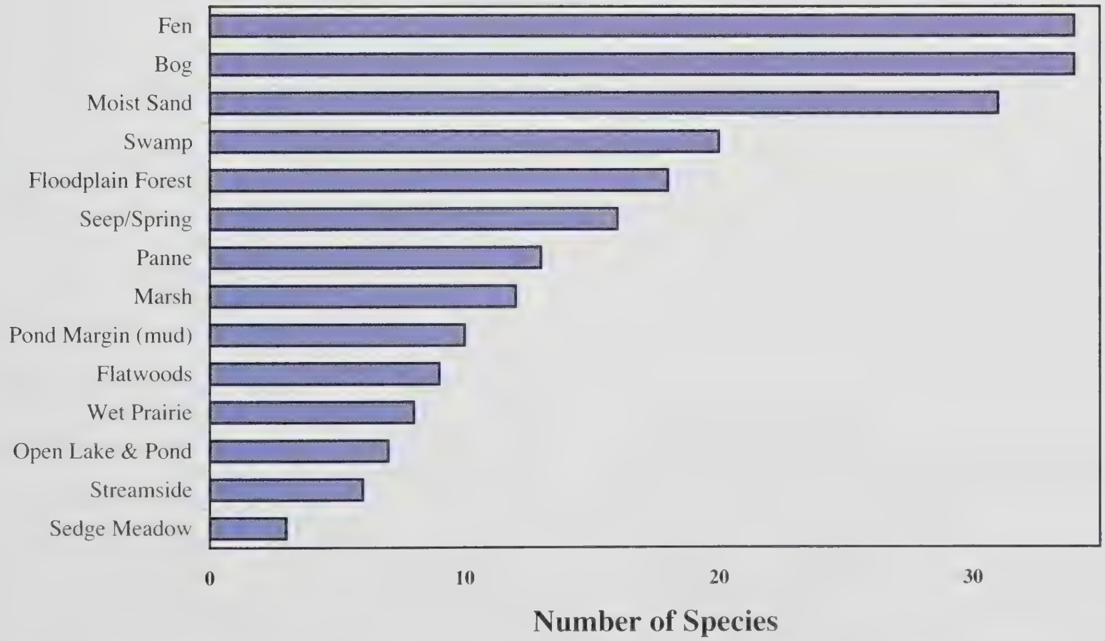

Figure 5.21. Number of wetland plant species listed as threatened or endangered in Illinois by natural community. Some species occur in more than one community (modified from Havera et al. [26]).

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CHAPTER 6

Fur, Scales, and Feathers; Changes to Illinois' Nongame Vertebrate Fauna

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OBJECTIVES

This chapter provides a brief history of four of the most important vertebrate groups in Illinois. We start with background information for amphibians and reptiles, as they are often the least familiar and most poorly understood group. Each section starts with our historical understanding of the groups, beginning with the early accounts of European settlers and naturalists and continuing with the major contributions of Illinois Natural History Survey scientists. We finish with thoughts of what the future holds for these important animals in Illinois.

AMPHIBIANS AND REPTILES

"May 15, 1890, my son and I went over to West Prairie. The night before the water from Cahokia Creek had overflowed the whole prairie from 3 to 6 inches. On every small elevation or heap of ground we found several Massasaugas, utterly exhausted. Within two hours we had collected fifty-nine, mostly half grown, but some very large specimens – over 730 mm. long. We searched for the sixtieth but did not find it. We packed the fifty-nine in two medium sized minnow buckets and found them all alive on reaching home some three hours later.

…At present a large part of that prairie has been drained and cultivated, and the Massasaugas have disappeared."

This excerpt from Julius Hurter (1), in reference to an area in Madison County in southwestern Illinois, makes it very clear that at the close of the nineteenth century, reptile populations in Illinois were already negatively impacted by land alteration for agricultural use.

BACKGROUND INFORMATION

Although amphibians and reptiles are not each other's closest relatives, they have traditionally been studied together under the discipline of herpetology because they share many habits and are outwardly similar. During the early development of classification and taxonomy in the 1700s, they were considered "lower forms" and not worthy of detailed investigation. The great classifier of biodiversity, Carolus Linnaeus, grouped them together in the class Amphibia along with cartilaginous fishes (sharks and rays). It was clear that Linnaeus had a dim impression of amphibians and reptiles, referring to them as foul, loathsome, and abhorrent "because of their cold body, pale color, cartilaginous skeleton, filthy skin, fierce aspect, calculating eye, offensive smell, harsh voice, squalid habitation, and terrible venom…." With further study came the realization that, although they share general similarities, there are important differences between amphibians and reptiles. This view was first published in 1825 by Pierre-Andre Latreille, a French priest and naturalist, who split amphibians and reptiles into distinct groups in his book *Familes Naturelles du Regne Animal* (2). Chief among these is the relationship to moisture. Amphibians are constrained to wet or moist environments because their skin and egg membranes are permeable to water. Reptiles, on the other hand, are less dependent on water because they have a scaly waterproof skin and their eggs are protected by a thick shell. As Charles Darwin's theory of evolution through natural selection became more widely accepted in the late 1800s, the view of amphibians shifted from a lower form not worthy of study to the focal point for the evolution of terrestrial vertebrates. It is now widely recognized that amphibians and their ancestors form the basal branch of all living tetrapods (four-legged animals).

Although Linnaeus noted "their Creator has not exerted his powers to make more of them" amphibians and reptiles account for almost half of extant tetrapod species. Within this group exists an incredible diversity of ecology, behavior, morphology, and physiology. Their diversity and importance to the ecosystems they inhabit have often been overlooked because of their generally secretive nature. This has changed over the past 50 years as the various roles of amphibians and reptiles have been documented. Amphibians and reptiles function as consumers and a food source in many food chains; larval amphibians, especially tadpoles, have significant impacts in nutrient cycling. Through their breeding migrations, amphibians transfer energy between aquatic and terrestrial systems, and both groups contribute to soil dynamics by their burrowing activities (see [3] for a

Figure 6.1. Redback Salamander, *Plethodon cinereus*. Photo by M. Redmer.

review of salamander importance). As an example of the ecological importance of amphibians, Burton and Likens (4) estimated the density of Redbacked Salamanders (*Plethodon cinereus*—Fig. 6.1) at over 2,600 per hectare at the Hubbard Brooks Experimental Forest in New Hampshire. This is higher than the number of birds during peak breeding season and about equal to the number of mice and shrews at this site, both in terms of numbers and dry weight. In addition, Redbacked Salamanders can indirectly slow the rate at which leaf litter is broken down by reducing soil invertebrate abundance (5). This results in regulation of the carbon-nitrogen cycle via longer retention of nutrients in the soil over time. Another example of the role of amphibians concerns trophic interactions. Brodman et al. (6) compared the density of mosquito larvae in 12 wetlands with salamander larvae (genus *Ambystoma*) against 12 wetlands without salamander larvae and found it to be 98% lower in the wetlands with salamander larvae. Finally, there is the importance of amphibians as indicators of ecosystem health and integrity. There is a suite of features unique to amphibians that make them particularly useful gauges of the condition of their environment. Most amphibians have a two-part life cycle; eggs and young are aquatic and adults are at least partially terrestrial. This means they sample both ecosystems in their life cycle. They have moist, sensitive skin that allows chemicals in the environment to pass into their bodies and their eggs lack a hard shell so their developing young are also directly exposed to the environment.

Worldwide, we currently recognize over 6,500 species of amphibians divided into three groups, Anura (frogs), Caudata (salamanders), and the incompletely studied Gymnophiona (caecilians). The 8,000 plus species of reptiles are commonly grouped into Testudinata (turtles), Squamata (lizards and snakes), and Crocodylia (crocodilians).

A BRIEF HISTORY OF AMPHIBIAN AND REPTILE RESEARCH IN ILLINOIS

The first published mention of amphibians and reptiles in Illinois was by Thomas Say (7) and appeared not long after Illinois became a state. Thomas Say was a physician and accomplished naturalist who served as a zoologist on Major Stephen Long's 1819–1820 expedition from Pittsburgh to the Rocky Mountains. The group traveled by steamboat down the Ohio River and Say observed a Map Turtle (*Graptemys geographica*) laying eggs on the banks of the river near Shawneetown (cited in 8). The first attempt at a comprehensive list of amphibian and reptile species for Illinois appeared 60 years later when Davis and Rice (9) published their checklist. From this point on, Illinois Natural History Survey staff figured prominently in the development of herpetology in Illinois, starting with Harrison Garman's *A Synopsis of the Reptiles and Amphibians of Illinois* (10). This was followed in 1961 by Philip Smith's *Amphibians and Reptiles of Illinois* (8), considered to be the best of the regional herpetology treatments of its time and among the first to use "dot maps" with background shading to show the presumed Illinois range. For this project, Smith compiled data from approximately 8,000 specimens in the INHS collection, Illinois records from other United States museums, and statewide fieldwork from 1947–1953. No one has contributed more to Illinois herpetology, or probably ever will, than Phil Smith. After the publication of *Amphibians and Reptiles of Illinois* (8), Smith's attention turned almost exclusively to fishes (see Chapter 9). The herpetology portion of Smith's position would not be filled for many years, so for most of the second half of the twentieth century and until the hiring of the senior author by INHS in 1993, Illinois herpetology was largely dominated by scientists at other Illinois institutions; notably Ronald Brandon at Southern Illinois University - Carbondale, Edward Moll at Eastern Illinois University, and Lauren Brown at Illinois State University. The twentieth century came to a close with the most recent treatment of the amphibians and reptiles of Illinois by Phillips et al. (11). This field guide contained distribution maps, color photographs, natural history data, and identification keys for all Illinois species.

CHANGES IN DISTRIBUTION AND ABUNDANCE OVER TIME

Smith (8) listed 35 species of amphibians and 58 species of reptiles in Illinois. Since that time six amphibians and two reptiles have been added to the Illinois list (11). Two of the amphibians, the Silvery Salamander (*Ambystoma platineum*—Fig. 6.2) and the Jefferson Salamander (*Ambystoma jeffersonianum*) were known from Indiana near the Illinois border, but had not been previously documented in Illinois. One of the newly added frogs, Cope's Gray Treefrog (*Hyla chrysoscelis*), had been confused with the morphologically identical Gray Treefrog (*Hyla versicolor*) until it was recognized as a separate species in 1966 (12). The two species differ only by male mating call and chromosome number. The other three newly added frogs, the Plains Leopard Frog (*Rana blairi*), the Southern Leopard Frog (*Rana sphenocephala*), and the Upland Chorus Frog (*Pseudacris feriarum*) were added to the Illinois list as a result of elevation of subspecies to full species status or recognition of a cryptic species. The two reptiles that

were added to the Illinois list, the Ouachita Map Turtle (*Graptemys ouachitensis*) and the Eastern Ribbonsnake (*Thamnophis sauritus*) were both recognized as subspecies at the time of Smith (8) and were later elevated to full species (13, 14). Smith (8) acknowledged the possibility that both subspecies might occur in Illinois, but taxonomic uncertainty at the time prevented him from drawing definitive conclusions.

Since the publication of Smith (8), at least two species, the Eastern Hellbender (*Cryptobranchus allegeniensis*) and the Alligator Snapping Turtle (*Macrochelys temmincki*), have been observed so rarely that they are considered extirpated in Illinois by some herpetologists. Neither species was ever considered common in the state, their ranges reaching Illinois only marginally. However, their apparent decline was hastened by destruction and deterioration of suitable habitat. The Hellbender is a totally aquatic salamander that respires directly through its skin (15). Thus, they require clear, fast flowing rivers and streams (Fig. 6.3) to derive sufficient oxygen (16). In addition, they need large submerged rocks for cover and reproduction (17). The few rivers and streams in Illinois where Hellbenders were historically recorded no longer contain suitable habitat as land use practices in the past 100 years have changed dramatically. The conversion of large tracts of land to agriculture (Chapter 4) has lead to an increase in siltation in formerly clear streams. The suspended solids in streams interfere with oxygen uptake. The Alligator Snapping Turtle (Fig. 6.4) inhabits Cypress-Tupelo swamps and large river backwaters with the bulk of its range south of Illinois (18). There are only a handful of historical records for the species in Illinois and all are in extreme southern Illinois. There is no documentation of breeding by this species in Illinois and it is unclear whether the Illinois records represented transient individuals or residents.

The Alligator Snapping Turtle and the Hellbender, along with nine other species of amphibians and reptiles, are listed as endangered in Illinois. In addition, there are 13 species listed as threatened (Table 6.1), which means that 24% of the state's species (19.5% of the amphibians and 26.6% of the reptiles) are listed as threatened or endangered. As a comparison, 14.5% of the state's mammals and 16% of the state's breeding birds are listed as threatened or endangered. The number of threatened and endangered amphibians and reptiles in Illinois closely matches those for other Midwest states (Table 6.1). This fact is likely due to similar patterns of habitat alteration found across the central United States.

Other species have undoubtedly declined over the past 150 years in Illinois, but the secretive nature of most amphibians and reptiles makes it difficult to efficiently monitor changes in abundance over an area as large as Illinois. Some species have been targeted for statewide surveys, usually as a result of a review of status requested by the state or the federal governments to aid in decisions about listing as threatened or endangered. In most of these cases, the species was already declining when the study was carried out, so there were relatively few populations

Figure 6.2. Silvery Salamander, *Ambystoma platineum*. Photo by M. Ignoffo.

Figure 6.3. Fast-flowing stream. Ideal Hellbender habitat. Photo by C. Philllips.

Figure 6.4. Alligator Snapping Turtle, *Macrochelys temmincki*. Photograph by M. Jeffords.

Table 6.1. Total species and number and percentage listed as endangered or threatened for amphibians and reptiles in five Midwest states.

	Amphibians			Reptiles			Total		
State	Total # Species	# Listed	% Listed	Total # Species	# Listed	% Listed	Total # Species	# Listed	% Listed
Illinois	41	8	20%	60	16	27%	101	24	24%
Indiana	38	5	13%	58	15	26%	96	20	21%
Iowa	22	4	18%	46	15	33%	68	19	28%
Missouri	43	1	2%	63	7	11%	106	8	8.5%
Wisconsin	19	1	5.2%	34	9	26%	53	10	19%

to survey. Examples of such species surveyed include the Bird-voiced Treefrog (*Hyla avivoca*—Fig. 6.5), Spotted Dusky Salamander (*Desmognathus fuscus*), Yellow Mud Turtle (*Kinosternon flavescens*), and Kirtland's Snake (*Clonophis kirtlandi*) (19, 20, 21, 22). The Yellow Mud Turtle and Kirtland's Snake were found at only a fraction of their historical locations, while the Dusky Salamander and the Bird-voiced Treefrog appear to be holding steady. Other species have also been examined for changes in distribution, but these have generally been those originally restricted to a small portion of the state such as the Green Treefrog, *Hyla cinerea* (19) or of particular interest to a researcher such as the Plains Leopard Frog (23). In almost every case, the results indicate that the number of populations has declined and almost all declines can be traced to destruction or deterioration of habitat. The case of the Yellow Mud Turtle (Fig. 6.6) is a prime example. Studies in the late 1970s and 80s documented seven locality clusters in nine Illinois counties, but these have since been reduced to two localities (Phillips unpublished). Because Yellow Mud Turtles require two distinct habitats for their life cycle: open, unstabilized sand habitats for aestivation and hibernation plus sand ponds for foraging and mating, they are more susceptible to the effects of habitat destruction. Sand ponds in a suitable sand matrix in central Illinois have been drained or the sand habitat surrounding a suitable pond converted to agriculture. Either scenario has likely resulted in local extirpation.

An exception to the generally secretive behavior of amphibians and reptiles occurs in frogs, as the males signal their presence to other rival males or females during the breeding season with a species-specific call. During the appropriate time of year, frogs can be surveyed by listening for the males' calls. Recently, several standardized "frog call routes" have been established in the Chicago region and in southern Illinois. Volunteers drive pre-determined routes on secondary roads and stop at areas chosen ahead of time for their potential to harbor breeding frogs. The species identity and relative number of calling males are recorded. Repeated surveys within and among years can lead to an estimate of the population trends for each species. Although relatively new in Illinois, frog call routes hold promise for the future of amphibian population monitoring.

These limited studies do not allow an overall picture of amphibian and reptile decline in Illinois, but such an insight can be gained by looking at the destruction of habitat, by major type, in Illinois over the course of the twentieth century. Without a doubt, the black-soil prairie, or Grand

Figure 6.5. Bird-voice Treefrog, *Hyla avivoca*. Photo by M. Redmer.

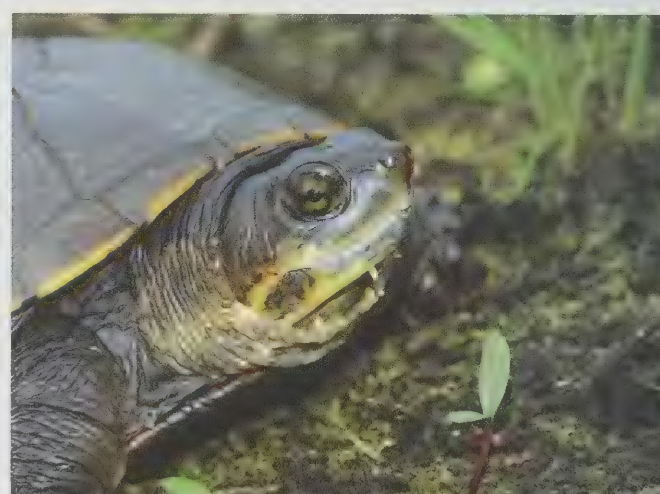

Figure 6.6. Yellow Mud Turtle, *Kinosternon flavescens*. Photo by J. Ross.

Prairie (Chapter 4), has suffered the most destruction, both in terms of total number and percentage of areas destroyed since European settlement. Even in the absence of rigorous surveys, it can be logically inferred that the amphibians and reptiles found in this habitat have also declined. One species that stands out in this regard is the Tiger Salamander (*Ambystoma tigrinum*). Garman (10) stated: "This is our largest and most abundant salamander. It resorts in great numbers to the ponds on prairies in early spring to deposit its mass of eggs." There were 10 positive locations for

this species from the Grand Prairie prior to 1960, but none have been observed since that time, even with a directed effort in the region (Fig. 6.7). Certainly, other Grand Prairie amphibians and reptiles have suffered a similar fate.

In addition to habitat alteration, other biotic and abiotic factors, such as increased levels of herbicides, pesticides, organochlorides, and UV radiation reaching amphibian and reptile habitats have been implicated in large-scale losses across the United States and the world. Perhaps the most frightening issue faced today is the global decline in amphibian populations, especially frogs and toads, even in pristine areas of the world. Recent evidence points to a fungal disease, chytridiomycosis, as the most likely cause of this faunal collapse (24). This pathogen has been responsible for massive die-offs of frog and toad populations from Central America to Australia (25). Scientists have yet to identify the actual mechanism of mortality, but not all species seem to be affected, which gives hope for future research. Although there have been no documented die-offs in Illinois or the Midwest as a result of chytridiomycosis, scientists in Illinois are conducting surveys for the pathogen in hopes of staying ahead of possible outbreaks (K. Lips, SIU-C, pers. comm.).

THE FUTURE

The fate of amphibians and reptiles in Illinois over the next 150 years is a mixed bag. On the one hand, new programs designed to provide incentives for private landowners to protect and restore critical habitats have promise. The Illinois Wildlife Action Plan, which was implemented in 2006, outlines specific steps that are needed to ensure survival of all wildlife species in the state. Included in this plan is a list of "Species in Greatest Need of Conservation" of which 14 are amphibians and 23 are reptiles. Federal funding to support implementation of the plan has already been directed to research projects on several amphibian and reptiles species and will hopefully provide more in the future. On the other hand, global climate change could alter species distributions, leading to possible extirpation of some of the more cold-adapted species such as the Four-toed and Blue-spotted Salamanders, while at the same time opening the door for more southerly species to move north. In addition, agricultural practices in Illinois may be profoundly affected by the search for alternative energy in the form of bio-fuels. Whether corn-based ethanol production continues to increase or is supplanted by more efficient crops such as *Miscanthus* will have a drastic effect on the habitats available for amphibians and reptiles in Illinois because these cellulose-based crops should provide more accommodating habitats than does corn. Because amphibians and reptiles are not generally as charismatic as birds or mammals, public opinion will also play a critical role in the future of these "foul and loathsome creatures."

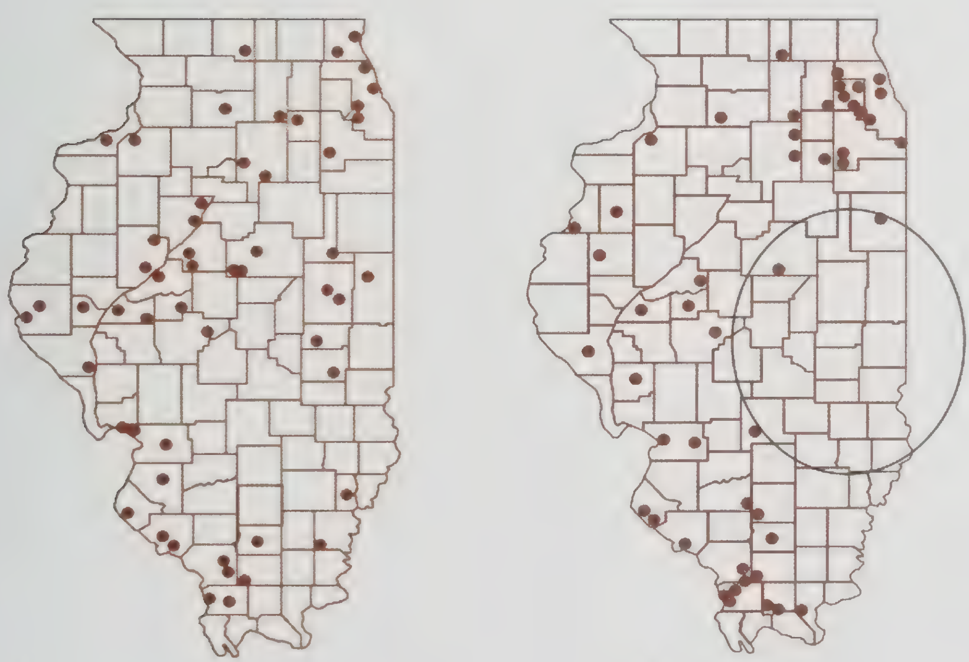
A B

Figure 6.7. Maps of Tiger Salamander, *Ambystoma tigrinum*, museum records for Illinois. (A) up to 1960. (B) 1961 to present. The circle represents the approximate location of the Grand Prairie Natural Division.

BIRDS

"The first visit to Fox Prairie was made on the 8th of June, 1871...our ears were delighted by such a chorus of bird-songs as we have heard nowhere else. Many kinds of birds were seen, but to name them all would require too much space....Nor must we forget a pair of croaking ravens who, after circling about for a short time over a border of the woods, flew away to the heavy timber in the Fox River bottoms.... A novel spectacle of numerous exquisitely graceful Swallow-tailed Kites floating about on buoyant wing, now gliding to the right or left, then sweeping in broad circles...the sight was beautiful in the extreme....Early in June, 1883 - exactly twelve years after the first trip. The change which had taken place in the interval was almost beyond belief. Instead of an absolutely open prairie some six miles broad by ten in extreme length, covered with its original characteristic vegetation, there remained only 160 acres not under fence. With this insignificant exception, the entire area was covered by thriving farms, with their neat cottages, capacious barns, fields of corn and wheat, and even extensive orchards of peach and apple trees. The transformation was complete."

This description by Robert Ridgway (26) involving a relatively small (38,000 acres) native prairie remnant in Richland County in southeastern Illinois in late nineteenth century Illinois, exemplifies Illinois's rapid change to the agricultural landscape. Many species such as the previously mentioned Swallow-tailed Kite (*Elanoides forficatus*) and Common Raven (*Corvus corax*) are now extirpated from the state.

A BRIEF HISTORY OF BIRD RESEARCH IN ILLINOIS

The initial study of birds within Illinois began mostly through the sightings and collection efforts of dedicated "bird watchers" and collectors. These collectors were interested not only in birds themselves but also their nests and eggs; oology (study of eggs) was very popular and personal egg collections were common among people interested in nature. The first published list of birds for Illinois was provided by Kennicott (27), in his list of animals observed in Cook County, 36 years after Illinois's statehood in 1818. This was followed by a list of birds in northeastern Illinois in 1876 (28). The most important early publications were commissioned by Dr. Stephen A. Forbes for the Illinois State Laboratory of Natural History, (as the Illinois Natural History Survey [INHS] was known at the time). Dr. Forbes commissioned *Ornithology of Illinois* (26, 29), a two-volume book authored by Dr. Robert Ridgway of Mt. Carmel, Illinois. These volumes were the first accounts of birds for Illinois and one of the finest sources of ornithological information available during that time. Dr. Ridgway was considered one of the chief authorities on the birds of North America, and served as the Curator of Ornithology at the Smithsonian Institution.

As the State Entomologist, Forbes not only studied insects, but conducted many studies of the diet of birds, their life history characteristics, and how birds interacted with their environment, humans, and agriculture. Several of Forbes' writings and scientific papers established the emerging field of ecology, including the concept of the ecosystem and other basic ecological concepts (30). Other papers by Forbes (31) addressing the diet of birds were quantitative attempts to determine whether birds could reduce the abundance of insect pests, a subject of much concern to farmers and horticulturalists of the time, and is still an active area of investigation today. This topic, as it related to birds, became known as "economic ornithology" and eventually was a factor leading to the protection of all native birds via the 1918 Migratory Bird Treaty Act. Forbes' most important and lasting contribution to Illinois ornithology may have been the statewide bird survey, which was the most comprehensive bird survey of its time. This survey began in 1906, with Alfred Gross and Howard Ray conducting a cross-state bird census covering 2,825 miles of travel on foot across transects in the northern, central, and southern portions of Illinois. This census is believed to have been the first quantitative analyses of bird populations in North America (32).

Because of the unique nature of this early census, a second statewide bird survey was conducted 50 years later. The result of this second survey, conducted by INHS biologists Richard and Jean Graber, was published as "A comparative study of bird populations in Illinois, 1906–1909 and 1956–1958" (33). This publication provided an often-used reference to the changes in bird populations. The 1956 census highlighted the decline in species such as Bewick's Wren (*Thryomanes bewickii*), Greater Prairie-Chicken (*Tympanuchus cupido*—Fig. 6.8), and Eastern Bluebird (*Sialia sialis*). Analyses of the population trends for many species provided a reference and backdrop for the future research documenting and understanding large-scale population declines (i.e. conservation biology).

In 2006, researchers at INHS again repeated the statewide bird survey by returning to the exact sites where ornithologists 50 and 100 years earlier censused the bird communities using the same sampling methodologies. Preliminary results indicate large changes in both the distribution and abundance of many bird species (see below). This survey, when combined with data from the two previous surveys will provide a benchmark to evaluate the decline of birds over a large spatial scale and represent perhaps the most complete record of change in bird abundance and distribution in the world.

CHANGES IN DISTRIBUTION AND ABUNDANCE OVER TIME

Extinctions, Extirpations, and Recoveries

Currently, 194 species of birds are recognized as breeding inhabitants of Illinois (34), compared to 196 species listed by Ridgway (26) and 164 listed by Gault (35). The differences among these lists are a result of extinctions, extirpations, and range expansions. Although there have been large changes in the abundance of many species, few species have gone

Figure 6.8. Greater Prairie-Chicken, *Tympanuchus cupido*. Photo by M.K. Rubey.

extinct. Robert Kennicott's (27) *Catalogue of Animals observed in Cook County, Illinois* lists only four species in Illinois that are now extinct: Eskimo Curlew (*Numenius borealis*), Passenger Pigeon (*Ectopistes migratorius*), Carolina Parakeet (*Conuropsis carolinensis*), and Ivory-billed Woodpecker (*Campephilus principalis*). Amazingly, the Passenger Pigeon may at one time have been the most abundant bird in Illinois and on the planet. Both Kennicott (27) and Nelson (28) referred to it as an abundant migrant, although the last bird collected was in 1901 (36), and the species was considered extinct by 1914. Eskimo Curlews were also considered "rather common" to "common" by both Nelson (28) and Kennicott (27), respectively. Although not as abundant as the amazing numbers of Passenger Pigeons, the Eskimo Curlew's flocks reminded prairie settlers of the flights of Passenger Pigeons and the curlews were given the name of prairie pigeons. Their flocks contained thousands of individuals and would often form dense masses of birds extending half a mile in length and a hundred yards or more in width. When the flock would alight the birds would cover 40 or 50 acres of ground. With "a few seen until at least 1880" (36), the Eskimo Curlew was considered "possibly extinct" in Illinois by 1922 (35). Due to demand for their feathers for use in women's hats, the Carolina Parakeet was described even in John James Audubon's day as "fast disappearing" (35), and the species was gone in Illinois by the end of the nineteenth century (37). While its range-wide demise has received much historical and recent attention, little was written of the Ivory-billed Woodpecker in Illinois, with all accounts of sightings occurring in the late nineteenth century near the southern tip of the state (37).

Although most of the above species shared a fairly broad range, as well as a large/abundant population, they all succumbed to a relatively rapid pace of decline, due to overhunting throughout their range. Other species became extirpated from Illinois as a breeding species, often as a direct consequence of habitat loss coupled with persecution by humans. These include the Trumpeter Swan, *Cygnus buccinator*, (although a reintroduced population is expanding into the state), Sharp-tailed Grouse (*Tympanuchus phasianellus*), Common Loon (*Gavia immer*), Whooping Crane (*Grus americana*—Fig. 6.9), Piping Plover (*Charadrius melodus*), Long-billed Curlew (*Numenius americanus*), and Common Raven. Other species such as Ruffed Grouse (*Bonasa umbellus*), Greater Prairie Chicken (Fig. 6.10) (See sidebar Greater Prairie-Chickens in Illinois), Sandhill Crane (*Grus canadensis*), and Barn Owl (*Tyto alba*) have been driven to the brink of extirpation due to a variety of human causations, including habitat loss and overharvest. Others, all of which are currently on the Illinois Endangered and Threatened Species List, include several species that have declined precipitously from their former abundance during pre-settlement times. These include the Upland Sandpiper (*Bartramia longicauda*), American Bittern (*Botaurus lentiginosus*), King Rail (*Rallus*

Greater Prairie-Chickens in Illinois—One of the first records of the Greater Prairie-Chicken in Illinois came from reports by French explorer Father Jacques Marquette. A member of his party collected a Greater Prairie-Chicken in the winter of 1674-75 at the present site of Chicago (101). These birds were undoubtedly an important part of the diet of early Native Americans, at least as early as 1200 A.D., as prairie-chicken bones have been found in Indian middens. Some tribes even imitated the birds in dances and costumes. However, as early as the 1870s, market hunters killed large numbers of Greater Prairie-Chickens throughout their range, with merchants in Chicago receiving approximately 600,000 birds per year, many of those harvested from Illinois (102). In addition, hundreds of eggs were often collected by settlers for consumption. This species probably reached its maximum density in the state during the 1860s, likely in the tens of millions, after early forest clearing and early agriculture made the Illinois landscape ideal for this species. In 1912, Dr. Stephen A. Forbes determined that this species was still present in 74 of Illinois' 102 counties. This had been reduced to only 25,000 birds in 1933 despite the closure of the prairie-chicken hunting season that year and to 40 counties by 1940. Only 24 counties contained prairie-chickens by 1955. The rapid decline continued as loss of grassland and nonrow crop agriculture (small hays, grain, pasture, alfalfa) left only 2,000 birds in the state by 1962, with fewer than 50 birds remaining at only two locations in 1993.

As intensive agriculture replaced much of Illinois's historic grassland habitats by 1940 the range of the prairie-chicken was limited to 50 square miles of sand prairie along the Green River in Lee County, and about 2,600 square miles of prairie in southeastern Illinois (103). Areas were purchased for the birds in Lee and Iroquois counties in 1940 and 1944, respectively, but unfortunately the prairie-chickens disappeared from these areas by 1960. For many years, the Greater Prairie-Chicken has been confined to two preserves in south-central Illinois in Jasper and Marion counties. Recent increases in the numbers of the remaining population appear to be the result of both translocations and reproduction from wild birds. These new introductions appeared to also provide increased genetic resources, which increased the viability of recent nesting attempts in Illinois (104).

elegans), Loggerhead Shrike (*Lanius ludovicianus*—Fig. 6.11), Northern Bobwhite (*Colinus virginianus*), Black-billed Cuckoo (*Coccyzus erythropthalmus*), Bewick's Wren, Red-headed Woodpecker (*Melanerpes erythrocephalus*), and Cerulean Warbler (*Dendroica cerulea*). The case of the Red-headed Woodpecker offers a prime example of the impact of habitat loss. Red-headed Woodpeckers prefer open savanna and woodlands with oaks, both habitat types that have declined precipitously in Illinois (see Chapter 4). The factors responsible for the decline in other species such as Bewick's Wren and Loggerhead Shrike are largely unknown.

Although the reduction in numbers of species was evident as long ago as the 1880s, the concern about the decline in bird populations reached its peak in the 1980s with the apparent decline of many breeding bird species that winter outside of the United States (neotropical migrants). Through research conducted at INHS, it was soon discovered that Illinois's small, fragmented forests supported high densities of Brown-headed Cowbirds (*Molothrus ater*) (38).

Figure 6.9. Whooping Crane, *Grus americana*. Photo by M. Jeffords.

Figure 6.10. Historic drawing of an organized hunt of Greater Prairie-Chickens, *Tympanuchus cupido*. Many references exist to hunting this species in Illinois on horseback. Artist unknown.

Figure 6.11. Loggerhead Shrike, *Lanius ludovicianus*. Photo by M. K. Rubey.

Cowbirds are brood parasites that prefer foraging in open agricultural areas, thus the fragmentation of forest due to agriculture provided the ideal habitat for this species. Brood parasites lay their eggs in other bird's nests, and their young are more aggressive than the host young, thus out-competing them for food resources and nest space. The overall effect is that birds that do not have defenses against brood parasites (most forest birds) produce fewer young. Many of the forest species in most serious decline were the species (e.g. vireos, warblers, tanagers) that were found to be most affected by Brown-headed Cowbirds (38). Additional research on grassland, wetland, and shrubland species suggests that the greatest single threat to birds in Illinois and the world is the loss and alteration of habitat.

Fortunately, many species are also increasing in population. One of the most stunning examples is the Canada Goose (*Branta canadensis*). Currently, this species can be seen throughout Illinois nesting in such extreme locations as the tops of buildings and ornamental plantings in parking lots. The Canada Goose was once described as "abundant" by Kennicott (27), but later termed "very doubtful as a breeder at present day" by Gault (35). The "Giant" Canada Goose race, which was thought extinct but re-discovered by INHS scientist Dr. Harold Hanson in Minnesota (39), has recovered so completely as to be considered a nuisance species. Another example of an amazing recovery is that of Wild Turkeys (*Meleagris gallopavo*). Once extirpated from Illinois by over hunting, multiple reintroductions failed until the correct subspecies of turkey was introduced. Since its reintroduction, the species has expanded to occupy every county of Illinois (see Chapter 8). Other species have also increased in abundance; these include the Bald Eagle (*Haliaeetus leucocephalus*), the Black Vulture (*Coragyps altratus*), the Double-crested Cormorant (*Phalacrocorax auritus*), and the Wood Duck (*Aix sponsa*). Some of these species, especially the fish-eating species (eagles, cormorants, herons, egrets), have benefited from the improvement in water quality throughout the state.

The Northern Cardinal (*Cardinalis cardinalis*) in 1906 was found only in the southern third of the state;

however, by 1956 it was found throughout the state, although it was uncommon in northern Illinois. Currently this species is one of the most common species across the entire state (Fig. 6.12). There are several other species that appear to be expanding their ranges north; these include Red-bellied Woodpecker (*Melanerpes carolinus*), Tufted Titmouse (*Baeolophus bicolor*), Turkey Vulture (*Cathartes aura*), Carolina Wren (*Thryothorus ludovicianus*—Fig. 6.13), Mourning Dove (*Zenaida macroura*), and Yellow-breasted Chat (*Icteria virens*). The reason for this large expansion northward is unknown, but researchers are investigating whether this expansion is due to changes in habitat, climate, or overall increases in populations.

Introduced species

In addition to several native species re-colonizing Illinois, several exotic species are now part of the avifauna of the Midwest. Although exotic bird species have not had the detrimental effects on habitats that a wide variety of exotic plant and aquatic animal species have had within the state (see Chapter 12), the initial colonization of the state by expanding populations of the European Starling (*Sturnus vulgaris*) and House Sparrow (*Passer domesticus*) have had a negative effect on a variety of cavity-nesting species (e.g. Purple Martin (*Progne subis*), Cliff Swallow (*Petrochelidon pyrrhonota*), Eastern Bluebird, and Red-headed Woodpecker). Invasive species such as Starlings can competitively exclude native species from breeding in tree cavities, thus forcing them not to breed or to breed in an area that is lower quality, producing fewer young. Populations of most of these species have recovered nicely due to nest box trails by various bird clubs, as well as a recent decline of both the European Starling and the House Sparrow. Numbers of Cliff Swallow colonies are likely beginning to approach their former distribution and population size throughout the state. Gray Partridge (*Perdix perdix*) and Ring-necked Pheasant (*Phasianus colchicus*) introductions by various government and private hunting organizations have filled the niche once occupied by the native Greater Prairie Chicken. The Rock Pigeon (*Columba livia*), as well as many European Starling and House Sparrow populations, filled the "new" habitats such as city parks and housing developments formed with the increasing human population and urban and suburban sprawl. Such city habitats have even provided a home to large numbers of the western North American native House Finch (*Carpodacus mexicanus*), a species that has spread westward from human released populations in the eastern U.S. Populations of some of Illinois's more recent or less established breeding exotic species are currently still spreading throughout various locations in the state, with the Monk Parakeet (*Myiopsitta monachus*—Fig. 6.14) and Eurasian Tree Sparrow (*Passer montanus*) being much more local in extent than the faster spreading populations of the Eurasian Collared-Doves (*Streptopelia decaocto*).

Figure 6.13. Carolina Wren, *Thryothorus ludovicianus*. Photo by M. Jeffords.

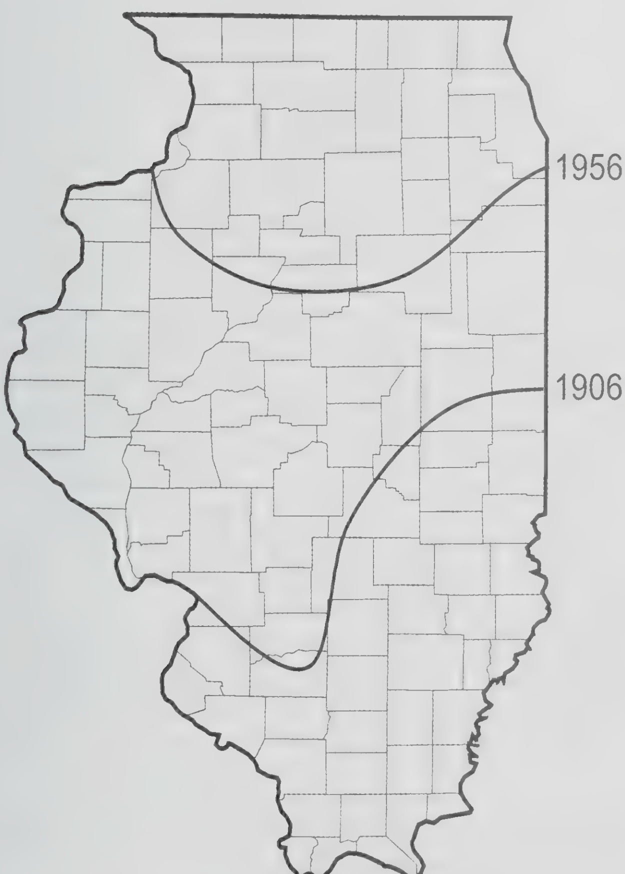

Figure 6.12. The distribution of Northern Cardinals over the last century. Currently Illinois' state bird is ubiquitous across Illinois, but in 1906 was only found in southern and east-central Illinois. In 1956 it was common throughout southern and central Illinois but had yet to colonize areas in northern Illinois.

THE FUTURE

Whether the next 150 years will bring about as dramatic changes to the avifauna of Illinois is debatable. Some models of global climate change suggest that many of the

Figure 6.14. Monk Parakeet, *Myiopsitta monachus*. Photo by M. Jeffords.

species currently present in Illinois will be gone from the state in the next century (e.g. Baltimore Oriole, *Icterus galbula*, and Veery, *Catharus fuscescens*). Even in the absence of climate change, changes in agriculture and land use practices that have profoundly altered the avifauna over the last 150 years, will continue to alter our environment. Although much of the changes over the last 150 years are viewed in a negative light, there is reason for optimism as society gains a greater understanding of the function our environment (including birds) has in promoting human health. Because birds are one of the most visible components of nature, it is crucial to understand and disseminate information regarding these species.

NONGAME MAMMALS

> *"far and near the prairie was alive with buffalo; now like black specks dotting the distant swell; now trampling by in ponderous columns or filing in long lines, morning, noon and night, to drink at the river—wading, plunging, and snorting in the water; climbing the muddy shores; and staring with wild eyes at the passing canoes."*

This scene, translated from the journals of Rene-Robert Cavelier, Sieur de La Salle and his companions as they descended the upper Illinois River in 1680, is one of the first European accounts of the Bison (*Bison bison*) that once roamed the state (40).

A BRIEF HISTORY OF NONGAME MAMMAL RESEARCH IN ILLINOIS

The lives of mammals inhabiting Illinois have long been of economic and aesthetic interest to naturalists, artists, photographers, hunters, and trappers. However, until the mid-nineteenth century, most recorded information consisted of casual observations by early explorers, visiting naturalists, and settlers. In the 1850s, Robert Kennicott, avid ornithologist and author of the first list of birds of Illinois, published the first catalogues of mammals of Cook County (27) and Illinois (41, 42). Kennicott's catalog of mammals of Cook County was written at the request of the Secretary of the Illinois State Agricultural Society and was primarily an unannotated checklist of species of the state, based largely on his own observations. As an unpaid employee of the Illinois Central Railroad in 1855, Kennicott conducted a natural history survey along the railroad's right-of-way from Chicago to Cairo. His papers, published in the agricultural reports of the U.S. Patents Office, focused on mammals "injurious and beneficial" to Illinois farmers (41, 42). The reports of Robert Kennicott formed the basis for a list of species of Illinois mammals published in 1861 (43).

Half a century elapsed before additional significant reports on Illinois mammals emerged. In 1910 Arthur H. Howell described his collections of mammals from central and southern Illinois (44). Howell's work, based on permanently preserved specimens, is regarded as the first "scholarly account" of mammals of Illinois (45). Shortly thereafter, Charles B. Cory, Curator of Zoology at the Field Museum authored *The Mammals of Illinois and Wisconsin* (46). The work of Cory was an excellent, illustrated faunal survey of the two states and included species descriptions, detailed information on life history, geographic ranges in northeastern United States and southern Canada, and a list of specimens examined. The biogeographical work of Cory was the standard for information about Illinois mammals for the next three decades. Other significant papers on the biology of the state's mammals during the first seven decades of the twentieth century included faunal surveys focusing on the Chicago region (47) and southern Illinois (48, 49). In addition to studying mammals with commercial fur value (i.e. furbearers) (e.g. 50), Carl Mohr, a mammologist at INHS until 1947, published a paper giving the generalized geographical distribution of mammals within the state (51). The Illinois Natural History Survey published the first field guide to Illinois mammals, *Fieldbook of Illinois Mammals*, by Donald Hoffmeister and Carl Mohr in 1957 (52; reprinted in 1972 by Dover Press). Dr. Hoffmeister, Director of the University of Illinois Museum of Natural History, followed by authoring an encyclopedic compilation of information on the biology of the mammals of Illinois in 1989 (45). This comprehensive work discusses the natural environments of Illinois and its mammalian fauna from Pleistocene to present and contains accounts that include a narrative of physical, ecological, and behavioral characteristics and range maps in Illinois and North America for each current species. Finally, over one-half century after Hoffmeister and Mohr introduced the first field guide to Illinois mammals (long out of print), a second identification manual entitled *A Field Manual of Illinois Mammals* (53) by INHS mammalogist Joyce Hofmann was published in 2008.

CHANGES IN DISTRIBUTION AND ABUNDANCE OVER TIME

Extirpations and Population Declines

Today, Illinois is home to 60 species of mammals (53). These include the Virginia Opossum (*Didelphis virginiana*), White-tailed Deer (*Odocoileus virginianus*), rabbits (2 species), insectivores (7 species), carnivores (11 species), bats (12 species), rodents (25 species), and the Nine-banded

Armadillo (*Dasypus novemcinctus*). Cory (46) included the Star-nosed Mole (*Condylura cristata*) and the Spotted Skunk (*Spilogale putorius*) in his list, but there are no confirmed records for these species in Illinois.

During the nineteenth century seven species of mammals were extirpated from Illinois, largely as a result of human activities (45). These species include the Fisher (*Martes pennanti*), American Marten (*Martes americana*), Wolf (*Canis lupus*), Black Bear (*Ursus americanus*), Cougar (*Puma concolor*), Wapiti or Elk (*Cervus elephus*), and Bison (*Bison bison*). Three other species were virtually extirpated during the nineteenth century but have been re-established in the state, namely, American Beaver (*Castor canadensis*), North American River Otter (*Lontra canadensis*), and White-tailed Deer. The disappearance of these mammals was due, in part, to economic exploitation in the form of uncontrolled hunting and trapping for fur. In addition, mammals provided sustenance (meat) for settlers or were victims of overzealous predator-control programs. Lastly, the drastic alteration of the prairie landscape of Illinois to farmland plus harvesting of forests to provide lumber for settlers' houses contributed to the demise of the above species. There is limited information to document the occurrence or fate of all of these mammals, but some of their stories can be told with factual assurance.


Figure 6.15. Bison, *Bison bison*. Photo by M. Jeffords.

American Martens and Fishers declined dramatically during the nineteenth and early twentieth centuries because of woodland habitat destruction by logging and excessive trapping for fur. Prior to European settlement, both species of mustelids may have occurred in Illinois. Kennicott (54) indicated that the American Marten "…has been seen, occasionally, in Northern Illinois." Although there are no known specimens, Kennicott (54) also referred to the Fisher, stating "It has been found, within a few years, in Northern Illinois, and appears to be an inhabitant of the woods, alone." The distribution of Fishers in Illinois once may have been rather extensive as evidenced by remains of Fishers at prehistoric middens in the Cahokia Middle Mississippi Site near East St. Louis (55, 56).


Figure 6.16. Wapiti, *Cervus elephus*. Photo by M. Jeffords.

Bison (Fig. 6.15) were essential for the survival of people of the prairies; Native Americans relied greatly on Bison for food, shelter, blankets, and clothing. With the arrival of Europeans great numbers of Bison were slaughtered for skins, meat, and occasionally only for their tongues. Bison also were shot for the mere "sport" of it. Furthermore, European-Americans decimated herds of Bison as one tactic to subdue Plains Indians. Prior to the arrival of the first Europeans, the North American population of Bison numbered about 70 million. By 1900, numbers had dropped to fewer than 1,000 individuals (57). Bison occurred throughout Illinois when European explorers and settlers appeared, but not in the vast numbers that roamed the western Great Plains. By the beginning of the nineteenth century, the number of Bison in Illinois was greatly reduced due to a combination of hunting, habitat alteration, and severe winters in the late 1700s and early 1800s. We believe that wild Bison were extirpated in Illinois before 1830 (45).

Wapiti or Elk (Fig. 6.16) originally ranged throughout North America and Eurasia. Since the advent of European settlement, the Wapiti has been extirpated over most of its former range in North America. Early accounts suggest that Wapiti were common in Illinois during the

1700s (45). Although still present in the early nineteenth century, Wapiti probably were extinct in northern Illinois by the 1820s and southern Illinois by the 1830s (45). Today Wapiti reside chiefly in the Rocky Mountains and western states, as well as in small re-established populations across the continent.

Black Bears were encountered in much of Illinois until the mid-1800s and early explorers sometimes noted large numbers of them (45). As with Bison and deer, bears were exploited by explorers and settlers for food and hides. Reportedly, Native Americans seldom used bears as food, but did use their canines and claws in necklaces (45). The last bears were probably killed in central Illinois between 1821 and 1831; however, bears were still observed in Massac County in 1855. For all intents and purposes, bears probably were gone from Illinois by 1860 (45).

The Cougar, commonly called Cougar, Puma, or Panther was never reported from the northern half of the state and was already quite rare in Illinois by the 1800s. Hoffmeister (45) detailed accounts of Cougars in Illinois dating from the early to late 1800s. Reportedly, a man near St. Louis (in Madison County) killed seven Cougars during the winter of 1817 (45). In 1823 a Cougar was sighted at a sugaring camp in Vermilion County (58) and a nine-foot long animal was killed in Christian County in 1825 (59). In southern Illinois, Cougars were killed in Macoupin County in 1840 and Alexander County around 1862 (46). Cougars were most likely extirpated from Illinois before 1870 (45, 60).

The history of wolves in Illinois is complicated by the fact that many early writers did not distinguish between wolves and Coyotes, *Canis latrans* (45). In 1818, one of the first accounts of wolves in Illinois told of a large female wolf and her cubs attacking a Native American woman near Peoria (61). In 1826, wolves were reportedly so numerous in Schuyler County in west-central Illinois "…that they would chase the dogs clear to the cabin door…" (62). So common (and disliked) were wolves that bounties were placed on them. In 1825, the state offered a bounty of $1.00 for each wolf scalp; however, the price could be raised to $2.00 at the discretion of the county commissioner (45). By 1840–1850 wolves were rapidly disappearing in Illinois and *C. lupus* probably was extirpated from Illinois sometime prior to 1860 (45).

The White-tailed Jackrabbit (*Lepus townsendii*) is the only mammal extirpated from Illinois in the twentieth century! *Lepus townsendii* occurs from the Great Plains of Saskatchewan and Alberta east to extreme southwest Ontario down into Wisconsin and across the continent to the Rocky Mountains with a southern limit in central California. Our knowledge suggests that the eastern extension of the range of White-tailed Jackrabbits included eastern Iowa, southwestern Wisconsin, and the northwestern corner of Illinois (45). As indicated by Hoffmeister (45), "a perusal of the early literature on the histories of the counties in northwestern Illinois prior to 1900 gives no indication that White-tailed Jackrabbits were present." In 1947 a specimen was collected six miles west and one mile north of Hanover in Jo Daviess County and another was collected in 1954

Figure 6.17. The White-tailed Jackrabbit, *Lepus townsendii*. Photo taken at the Savana Army Depot by R. Nyboer.

on the Savanna Army Ordinance Depot (45). Because this area of the sand prairie provides excellent habitat for *L. townsendii*, a small population may have been established by natural movements either from Iowa or Wisconsin. *L. townsendii* has not been observed on this site since the mid-1980s (45, 63; Fig. 6.17). White-tailed Jackrabbits are considered as extirpated in Illinois; *L. townsendii* was removed from the list of Illinois endangered species in 1994.

In addition to these eight extirpated species, other mammals have experienced declines in abundance or range. The American Beaver played a major role in the settlement of North America. With prime pelts netting about $6.50 each during colonial times, the American Beaver was the backbone of the North American fur trade (57). Economic incentive attracted trappers to the west and they were followed by settlers. One estimate puts the total number of American Beavers in North America in pre-colonial times as high as 400 million (64). In a relatively short time, because of overharvesting, the beaver was brought close to extinction in North America. It is surprising that the nineteenth century did not result in the *complete* extirpation of beavers from Illinois. Beavers disappeared from many parts of the state by the 1860s and were close to extinction by 1900 (45). As Cory (46) indicated, "…at the present time they are practically exterminated in Illinois, although it is possible that a very few individuals may exist in the extreme southern portion of the state." Restocking of beavers, many from Wisconsin, was conducted between 1929 and 1938 and natural immigration from neighboring states probably occurred as well (65). By 1945, the species was widely established in Illinois once again and a trapping season was opened in 1951 (65). Today, American Beavers are common throughout the state.

Once widely distributed in grasslands throughout northern and central Illinois (50), Franklin's Ground Squirrels (*Spermophilus franklinii*) now show a patchy

distribution typified by low numbers (45, 66, 67). Evidence from examination of museum collections and live trapping confirmed a decline in populations of Franklin's Ground Squirrels in Illinois (67). Loss of suitable habitat is often cited as the major contributor to the decline in *S. franklinii* (68, 69, 70). In Illinois, they occupy habitats with medium-height grasses interspersed with weedy species of dicotyledonous plants in well-drained soils. Unlike Thirteen-lined Ground Squirrels (*Spermophilus tridecemlineatus*), they typically avoid areas of closely mown grass. The elevated track beds of railroad lines meet habitat needs of *S. franklinii* in Sangamon and Champaign counties, for example. Because there have been few sightings of this ground squirrel in recent years, it was designated a state-threatened species in 2004.

Range Expansions

Many mammals have been flexible enough to adapt to landscapes that consist of both natural and human-altered habitats, enabling them to persist in agricultural regions and inhabit towns and cities. A few mammals now are more common and widespread than in pre-settlement times. They have benefited from the elimination of large predators; supplemental food in the form of crops, garbage, and pet food left on porches; and the creation of additional edge habitat by the fragmentation of natural communities. Prime examples are the White-tailed Deer (Chapter 8) and Coyotes. Coyotes occur throughout Illinois, even in the heart of Chicago (71). Indicative of their abundance, hunters killed more than 125,000 Coyotes in Illinois during 2005 (72).

During the last 50 years, eight species of non-game mammals have expanded their ranges within Illinois (45, 73, 74). Species that have expanded their ranges southward in the state are Least Weasels (*Mustela nivalis*), Meadow Voles (*Microtus pennsylvanicus*), Western Harvest Mice (*Reithrodontomys megalotis*), and American Badgers (*Taxidea taxus*), while Beavers, River Otters, Southeastern Shrews (*Sorex longirostris*) and Masked Shrews (*Sorex cinereus*) have expanded in different directions. The tiny Western Harvest Mouse inhabits successional communities dominated by goldenrod and ragweed interspersed with grasses. We believe these mice arrived in Illinois in the 1950s, with the first records limited to the northwestern corner of the state (45). In only 20 years, the species had spread through northern and central Illinois and entered Indiana (e.g. 75, 76, 77). Another small mammal, the grassland-dwelling Meadow Vole, seems to have expanded its range by following the expanding interstate highway system. Prior to 1970, the southern edge of its range was just north of Champaign County. By 1976 meadow voles were found in Douglas County, a range expansion of 90 to 100 km (56 to 62 miles) to the south in only six years (73)!

Badgers are quite resilient and have adapted well to agricultural practices in Illinois, residing along railroad rights-of-way and roadside shoulders as well as in open areas (such as pastures). During the last half century, the range of Badgers seems to have expanded in Illinois, in part due to the availability of open terrain produced by removal of trees. Their presence now has been confirmed in 99 of the 102 counties in Illinois (78).

Another mammal has been advancing towards Illinois from the south—the Nine-banded Armadillo, *Dasypus novemcinctus*. With their bony carapaces, or shells, Nine-banded Armadillos are certainly unique among North American mammals (Fig. 6.18). A tropical species, the Nine-banded Armadillo ranges from South America to the southeastern and south-central United States. Its range in the United States has expanded greatly since the mid-1800s, with sporadic reports of occurrence in Illinois prior to 2000. Prompted by reports of recent sightings from IDNR biologists, mammalogist Joyce Hofmann of INHS decided to investigate the possible expansion of *Dasypus* into Illinois. In 2003 questionnaires asking about sightings of armadillos were mailed to 136 individuals considered knowledgeable about the fauna of southern Illinois and animal control agencies in 22 southern Illinois counties and municipalities. As of early 2008, at least 166 armadillos had been reported from 42 Illinois counties (Fig. 6.19; 79, 108). How can one explain this range extension? Some of it is certainly a result of human transport, both intentional and unintentional. The northward limit of the geographic range of *Dasypus* will be set by the severity of winter temperatures. Armadillos do not cope well with cold due to their high thermal conductivity, inability to enter torpor, and difficulty in obtaining insect food in winter at northern latitudes (80). Depth and duration of snow cover and prolonged periods of below-freezing temperatures likely influence survivorship of armadillos. The northern boundary of the armadillo's range will likely fluctuate from year to year, retreating southward as the result of harsh winters. Illinois south of the East St. Louis metropolitan region may be suitable for establishment of populations of Nine-banded Armadillos under favorable weather conditions. In light of trends in global warming, however, their range may extend even farther north in the not-so-distant future.

Figure 6.18. The Nine-banded Armadillo, *Dasypus novemcinctus*. Photo by M. Jeffords.

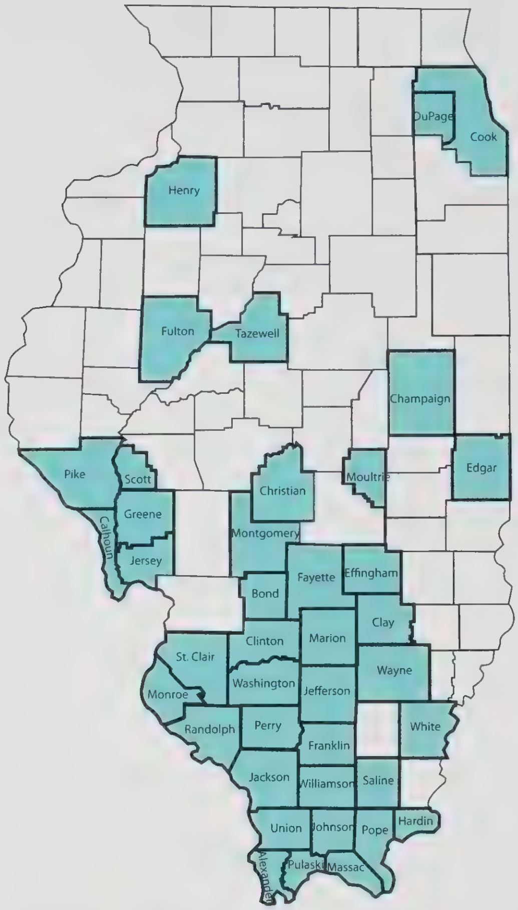

Figure 6.19. Illinois counties with documented records of the Nine-banded Armadillo, *Dasypus novemcinctus*.

ILLINOIS MAMMAL RECOVERIES—THE SUCCESS STORIES

The twentieth century was a time of deepened knowledge of mammals and their functional relationship with environments, resulting in a fundamental shift in attitudes (81). Knowledge gained from our mistakes of the past hopefully will aid in establishing our future stewardship objectives for the Illinois environment. The following case studies illustrate recent successful partnerships that focus on recovery of nongame species of mammals in our state.

Indiana Myotis and Magazine Mine

Illinois is home to 12 species of bats, all of which belong to the family Vespertilionidae, the most common North American family of bats. The Vespertilionids are mainly nocturnal and feed upon insects captured in flight. Because their food supply is not available year-round, bats of Illinois either hibernate during winter or migrate to warmer climates. The Indiana Myotis (*Myotis sodalis*) (Fig. 6.20), also called Indiana Bat, Social Bat, and Cluster Bat, is a small, brownish bat weighing about 6 to 9 g (0.2 to 0.3 ounces) and is similar in size and general appearance to the Little Brown Bat (*Myotis lucifugus*). Indiana Myotis are best known from their winter range where they hibernate in limestone caves and abandoned mines. Within a cavern, *M. sodalis* forms dense clusters of at least 3,000 bats/m^2 (300/ft^2) on rough ceilings or sidewalls (82). This behavior, which is distinctive for the species, accounts for the vernacular name of "Cluster Bat." The summer range of *M. sodalis* is not as well defined and information on the species' summer habitat requirements is limited. Some males probably remain near the hibernacula during summer, but it is not known where the majority of males go. Adult females do not form as large maternity colonies as do Little Brown Bats. Rather, small colonies bear their young beneath the exfoliating bark of dead or dying trees or the "shaggy" bark of certain live hickories and oaks (83). Indiana Myotis very rarely use buildings or other anthropogenic structures as summer roosts.

The U.S. Fish and Wildlife Service placed the Indiana Myotis on its list of endangered species in 1967. At present, the total population of this endangered species is approximately 457,000, with the majority hibernating in a few locations in Kentucky, Missouri, Indiana, and Illinois (83). Illinois is one of the strongholds for Indiana Myotis in North America. Seven Illinois caves and mines have served as important hibernation sites for *M. sodalis*: Blackball Mine (LaSalle County), Brainerd Cave (Jersey County), Brasher Cave (Pope County), Ellis Cave (Pope County), Fogelpole Cave (Monroe County), Toothless Cave (Jackson County), and Magazine Mine (Alexander County). Current numbers of Indiana Myotis hibernating in these caves range from 0 in Brasher Cave in 2001 to 43,509 in Magazine Mine in 2007 (Joe Kath, IDNR, pers. com.; 84). Brasher Cave experienced a 100% reduction in hibernating *M. sodalis* (from 500 bats in 1993 to 0 in 2001, Table 6.2), whereas, numbers of *M. sodalis* in Magazine Mine increased by 79% in only eight years, making it now the largest hibernaculum for *M. sodalis* in Illinois (85). How does one account for this dramatic increase?

In the 1900s, underground silica mining in Illinois was big business. One such venture was Magazine Mine belonging to UNIMIN Specialty Minerals Corporation, the world's largest producer of silica. Magazine Mine is located

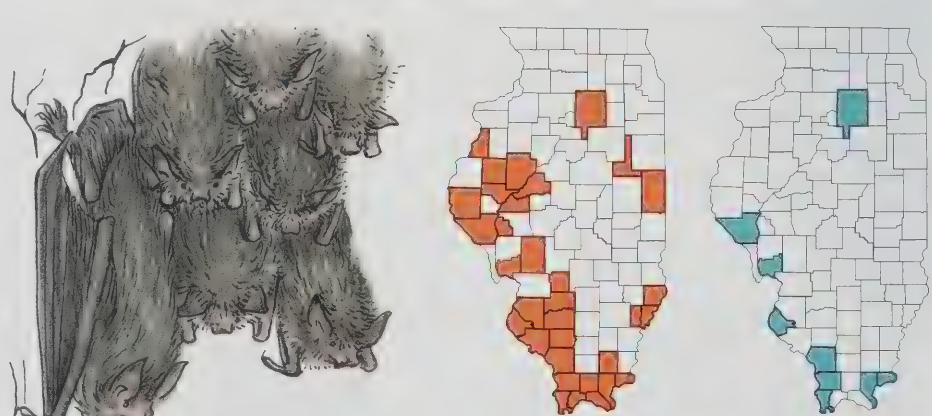

Figure 6.20. Indiana Myotis, *Myotis sodalis*. Red counties=bat's summer distribution. Blue counties=bat's winter distribution. Indiana Bat drawing by A. Holt.

Table 6.2. Hibernacula sites and census data for the Indiana Myotis, *Myotis sodalis*, documented by the Illinois Department of Natural Resources as of 2008. Adapted from Kath (85).

Hibernaculum	County	Historic Population size	Current Population size
Blackball Mine	LaSalle	260 bats (Feb. 1987)	1,338 (Feb. 2001)
Brainerd Cave	Jersey	150 (Feb. 1998)	426 (Jan.2000)
Brasher Cave	Pope	500 (Oct. 1993)	0 (Jan. 2001)
Ellis Cave	Pope	426 (Jan. 2000)	475 (Jan. 2001)
Fogelpole Cave	Monroe	403 (Jan. 1986)	171 (Jan. 2000)
Toothless Cave	Jackson	3,200 (Feb. 1995)	739 (Jan. 2000)
UNIMIN, Mine #30	Alexander	495 (Feb. 2000)	1,500 (Jan. 2001)
UNIMIN, Magazine Mine	Alexander	9,074 (Feb. 1999)	14,679 (Jan. 2001)
UNIMIN, Magazine Mine	Alexander		43,500 (2007)

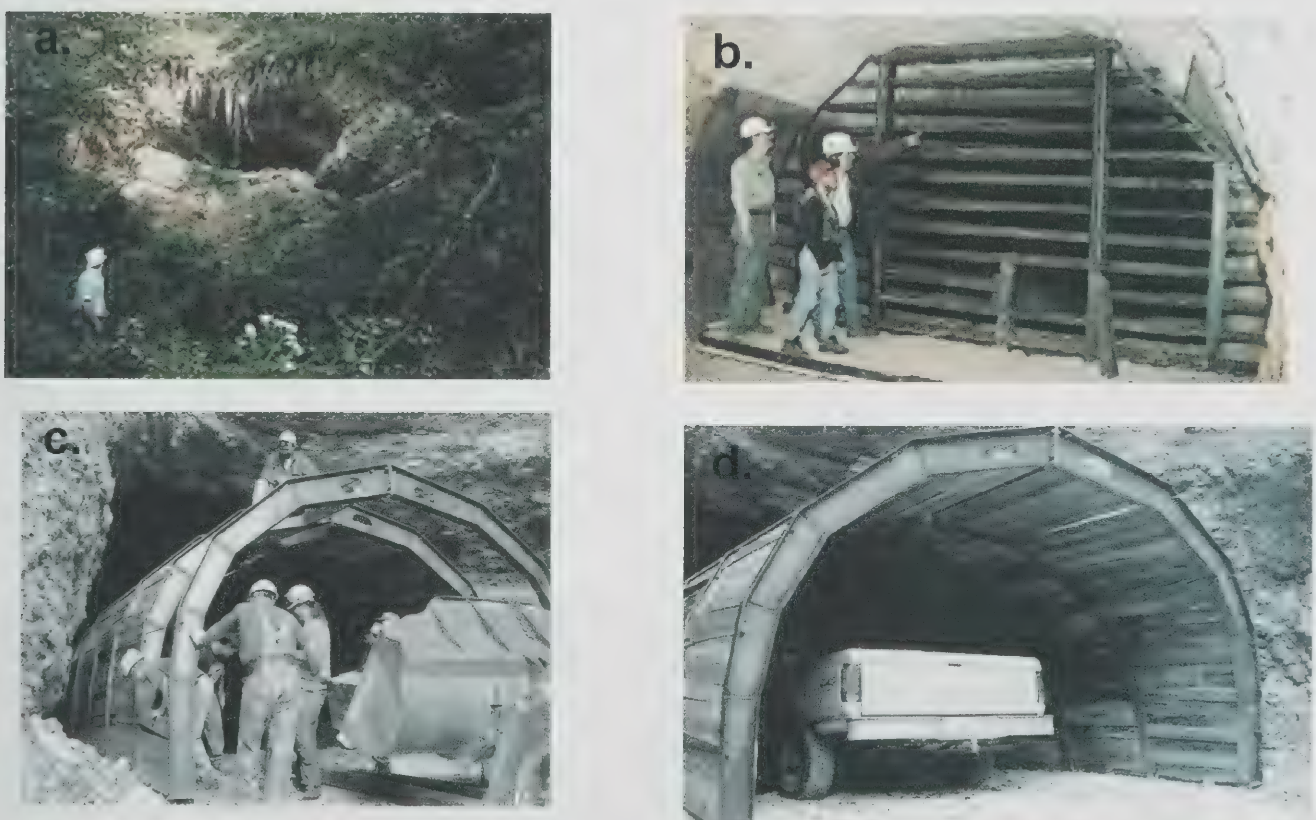

Figure 6.21. Magazine Mine (UNIMIN Corporation) showing the air shaft entrance, ca. 1972–1980 (a), bat-friendly gate installed in 1996 (b), and stabilization of main entrance, 2001 (c,d). From Kath (85).

in the Ozark Plateau of southern Illinois, much of it beneath Shawnee National Forest land (85). Encompassing 84,730 m^2 (20.9 acres), Magazine Mine is the largest abandoned underground silica mine in Illinois (Fig. 6.21). The mine opened in 1972, with operations ceasing in 1980. Some 4.2 km (2.6 miles) southwest of Magazine Mine is another substantial, yet smaller abandoned silica mine (UNIMIN Mine #30). Mine #30 operated from the mid-1960s until the late 1970s. This mine also serves as a crucial hibernaculum for *M. sodalis* (85).

Bat surveys conducted at an entrance to Magazine Mine during summer 1995 indicated that five species of bats inhabited the mine, namely, Big Brown Bats (*Eptesicus fuscus*), Little Brown Bats, Northern Bats (*Myotis*

septentrionalis), Eastern Pipistrelles (*Perimyotis subflavus*) and Indiana Myotis (85). Magazine Mine possesses two entrances, an "air shaft" entrance that was stable and a very large, but deteriorating "main" entrance that had been used by vehicles and mine personnel. A partnership including the Illinois Department of Natural Resources, U.S. Fish and Wildlife Service, U.S. Forest Service, Bat Conservation International, and UNIMIN was established to protect Indiana Myotis hibernating in the mine. A bat-friendly gate was constructed at the air shaft entrance of the mine in 1996. Because of the rapidly deteriorating nature of the main entrance, it was stabilized with a series of custom-designed steel arches covered with timber posts; construction was completed in August 2001. The Magazine Mine stabilization and protection project represents a unique cooperative partnership among private industry and state and federal agencies, with support from environmental organizations and local community groups. The success of the project represents a very positive step fostering environmental conservation and stewardship in Illinois.

Turkeys for otters: The River Otter Recovery Program

In the early 1800s, North American River Otters (Fig. 6.22) were reported as abundant along the Mississippi, Wabash, Illinois, Ohio, and Kankakee rivers and many other riparian localities of Illinois (45). Pelts sold for about $2.00 each—the highest price of any fur sold at Fort Dearborn (which became the city of Chicago) in the 1820s (45). As a result of over-harvesting for pelts and the loss of marshes and riparian areas, River Otters began to disappear and probably were close to extirpation in Illinois by the mid-1800s. By the early 1900s River Otters persisted mostly along the Cache River in southern Illinois. Despite a continuous closed harvest season since 1929, otter numbers continued to decline, with a few reports from scattered locations in the state (86). As the result of immigration from neighboring states, a breeding population became established along the Mississippi River and its tributaries in northwestern Illinois by the 1980s (86). River Otters were listed as threatened in Illinois is 1977 and reclassified as endangered in 1989. It was time to develop a plan for re-establishment of River Otters in Illinois.

The Illinois River Otter Recovery Program was established in 1994 under the leadership of IDNR's Division of Wildlife Resources. The beginning of this highly successful program entailed some rather creative bargaining by the IDNR. The founding population of 50 wild River Otters was acquired from Louisiana—in a circuitous fashion. These otters were purchased from a Louisiana supplier by the State of Kentucky and traded to Illinois for 75 Wild Turkeys! In all, 346 River Otters were released into watersheds of the Illinois, Kaskaskia, and Wabash rivers from 1994 through 1997. The IDNR has monitored population numbers and recorded and documented reproduction of otters in the wild (87). Between 1994 and 2002, otters expanded their numbers and distribution—by 2002 otters had been reported in 91 of 102 counties in Illinois. The species' status was upgraded to threatened in 1999 and in 2004 the Illinois Endangered Species Protection Board officially removed River Otters from the state list of endangered and threatened species. Today, River Otters thrive—populations have recovered from an estimated low of 100 otters in the state in 1970 to over 4,600 otters. The IDNR will continue monitoring the distribution and numbers of otters throughout the state. In addition to the diligent recovery efforts of IDNR biologists, improvement of water quality and protection of wetland and riparian habitats have contributed to the success of this species in the wild. Remediation and reduction of siltation, water pollution, and stream channelization are crucial to the success of the program.

Illinois pack rats

The Eastern Woodrat (*Neotoma floridana*—Fig. 6.23), also called the Pack Rat, Cave Rat, and Cliff Rat, reaches the northern limit of the midwestern portion of the geographic range in Illinois. At one time, Eastern Woodrats were found throughout southern Illinois, including the Shawnee Hills and Mississippi Alluvial Plain natural divisions (see Chapter 2), but they disappeared from the eastern portion of Shawnee Hills (45, 88). Surveys conducted in the 1990s indicated that Eastern Woodrats inhabited only four sites in the state, namely LaRue-Pine Hills, Fountain Bluff, Little Grand Canyon, and Horseshoe Bluff (89) (Fig. 6.24). For the most part, these populations were small, numbering < 100 individuals collectively in 1996. The largest population of *N. floridana* in Illinois occurred at the Pine Hills area, with small numbers at Fountain Bluff, Little Grand Canyon, and Horseshoe Bluff. Compared to more southern, continuous populations of Eastern Woodrats in Missouri, long-term isolation of the Illinois populations has resulted in reduced genetic variability, probably influencing reproductive vigor (90). Several researchers recommended translocation as a method of enhancing genetic diversity and establishing Eastern Woodrats in unoccupied habitats of southern Illinois. The stage was set for the Eastern Woodrats recovery plan.

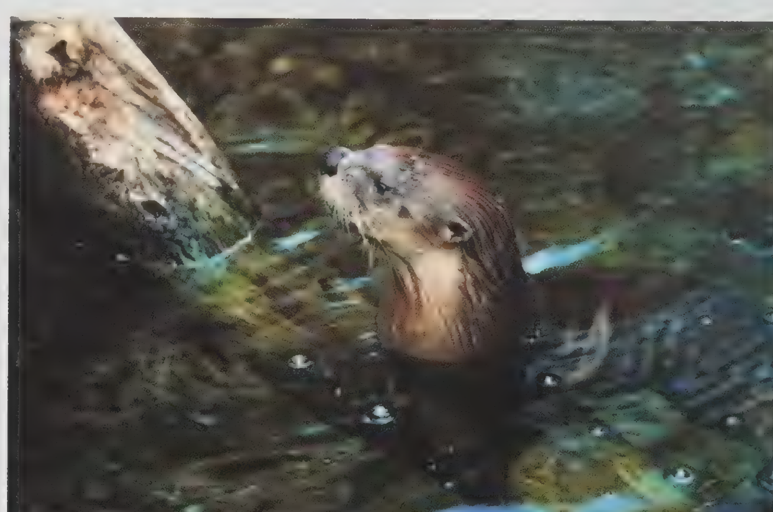

Figure 6.22. North American River Otter, *Lontra canadensis*. Photo by M. Jeffords.

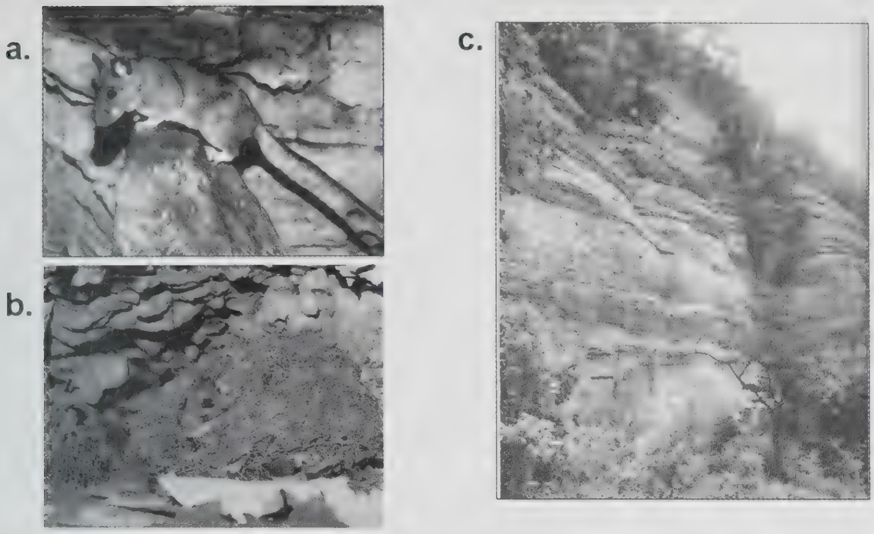

Figure 6.23. (a). Eastern Woodrat, *Neotoma floridana*. (b). Eastern Woodrat in den. (c) habitat of Eastern Woodrats in crevices and debris of the rocky bluffs along the Mississippi River floodplain near Wolf Lake, Union County, Illinois. Woodrat photos (a & b) from Merritt (57), by Hal S. Korber. Photograph of habitat (c) from Hoffmeister (45).

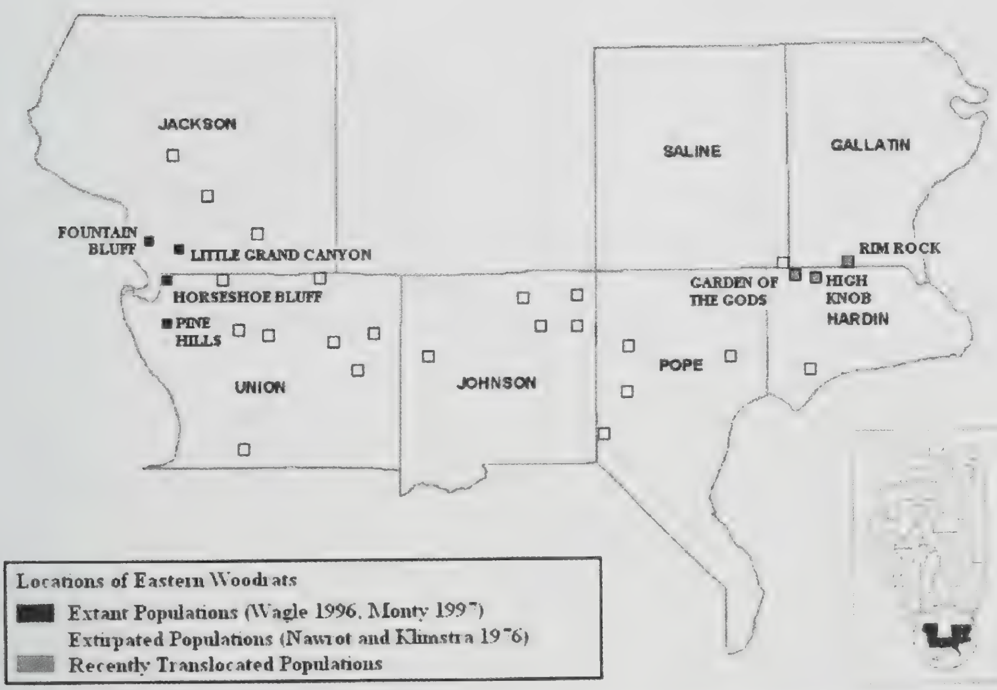

Figure 6.24. Map of southern Illinois showing previously extant, recently translocated, and extirpated sites of Eastern Woodrats, *Neotoma floridana*. (Adapted from 89, 91, 106, and 107).

Thirteen areas with suitable habitat in southern Illinois were identified as sites for translocating Eastern Woodrats (91). As of 2008, a total of 375 Eastern Woodrats captured in Missouri and Arkansas had been translocated to sites in southern Illinois by the Illinois Department of Natural Resources and Southern Illinois University. The populations of translocated individuals inhabiting the release sites are rated as stable. Population density and survivorship of released Eastern Woodrats is currently being monitored using mark-recapture methods. Radiotelemetry is employed to evaluate movement patterns of Eastern Woodrats. Survivorship of the Eastern Woodrats is favorable, and reproductive activity and recruitment of young have been noted in various populations. Early indications regarding the success of the Eastern Woodrats recovery program are promising and additional translocations and population monitoring are planned for the future.

Bobcats in Illinois

As with many other species of mammals, the numbers of Bobcats (*Lynx rufus*) in Illinois declined during the mid-1800s, attributable to removal of timber, persecution as a predator, overharvesting for pelts, and an open season for hunting. In the early 1900s, Bobcats were thought to be extirpated in the northern and central parts of the state but still present in southern counties, especially timbered areas along the Ohio, lower Illinois, and Mississippi rivers (45, 92, 93). Klimstra and Rosenberry (93) recorded sightings of Bobcats in southern Illinois and speculated that the species was more widely distributed than generally recognized. Novak et al. (94) listed high numbers of Bobcats in the state based on harvest data —an average of approximately 1,100 pelts were reported for four seasons in the late 1960s. Bobcats were fully protected by the Wildlife Code of 1971 (95). The Illinois Endangered Species Protection Board classified the Bobcat as threatened in the state in 1977. Following a decade of protection, the numbers of Bobcats remained low; between 1979 and 1982 there were only 89 reported Bobcat sightings in 52 counties (96). By the early 1990s it appeared that Bobcats were becoming more abundant in the state; however, to accurately define the health of Bobcat populations, long-term research was required. In response to this need, the IDNR

and Cooperative Wildlife Research Laboratory (CWRL) at Southern Illinois University began a joint research project in 1995 to monitor the population of Bobcats in the state. This project was supported by grants from Federal Aid to Wildlife Restoration (97). As a result of this long-term ecological study, Bobcats have been reported in 99 of 102 counties (95, 97, 98). During four winters, 96 Bobcats were live-trapped in southern Illinois and 76 were equipped with radiotelemetry collars to monitor movements of individuals. Biological and ecological information gained from these Bobcats can contribute to science-based management for Bobcats that reside in Illinois. Today, Bobcats are widely distributed in the state, although seldom seen. Their numbers are greatest in southern Illinois. In addition to the Shawnee Hills, the best Bobcat habitat is in the Kaskaskia River bottoms, lower Illinois River valley, and northwestern Illinois (95, 96). Because of their wide distribution and healthy, stable populations, Bobcats were removed from the list of threatened and endangered species for the state of Illinois in 1999.

NATURAL RECOLONIZATIONS

Two large mammals that were extirpated from Illinois during the nineteenth century could return to the state. The Wolf is expanding its range southward from the northern Great Lakes region. A healthy population inhabits northern Minnesota, northern Wisconsin, and the Upper Peninsula of Michigan (so healthy that this population has been de-listed; 99). Wolves dispersing from their natal packs can travel long distances in search of a territory of their own. Three confirmed wild wolves have been killed in Illinois since 2002—in Lake, Henry, and Pike counties. A Wolf killed in Indiana in 2003 was wearing a radiocollar that was attached in Wisconsin and likely traveled through Illinois. Another Wolf shot in Missouri in 2001 was wearing a collar from Michigan and might have moved through Illinois.

The Cougar seems to be expanding its range eastward. The number of Cougars in the West has increased over pre-settlement levels so there is pressure on individuals to disperse into new areas (100). A Cougar on the move can travel hundreds of kilometers. The number of White-tailed Deer also has greatly expanded, making the central and eastern United States good hunting grounds for Cougars. There have been at least seven confirmed Cougars in Missouri and three in Iowa. As of early 2008, three wild Cougars have been confirmed in Illinois (Randolph, Mercer, and Cook counties). Thus, there is potential for Illinois to become a wilder place in the future, but human attitudes will play a major role in determining if these two large carnivores could become established here again.

SPECIES OF POSSIBLE OCCURRENCE IN ILLINOIS

Porcupines remains were unearthed at prehistoric sites in southwestern and southeastern Illinois. Hoffmeister (45) indicated that he was unable to find reliable reports of porcupines residing in Illinois during the 1700s and 1800s, although E. dorsatum was observed in Indiana, within 64 km (40 mi) of the border of Illinois during the 1800s (105). Based on records of occurrence from northeastern Iowa and the southernmost counties of Wisconsin as well as adjacent Indiana, porcupines may have occurred in northern Illinois during pre-settlement times but been extirpated in the mid-to-late 1800s.

THE FUTURE

Forests represent crucial habitat for many species of mammals and management plans must seek to prevent further fragmentation of forest habitats in Illinois and delimit specific habitat requirements of each species. The mammalian fauna of Illinois likely could increase in the future as some species expand their geographic ranges. Today the face of Illinois is rapidly changing, primarily through urban sprawl. Expanding suburbs invariably result in conflicts with wildlife: alas, some people are not happy to have coyotes invade their backyards or bats take up residence in their attics. Typically such conflicts result in expedient solutions in the form of eradication of the mammalian invaders. One crucial role of environmental education and outreach will be to appeal to the public by tailoring information to address possible interactions of wildlife and humans by explaining both the scientific and intrinsic value of biodiversity to audiences.

SUMMARY

Although the loss of nongame vertebrates in Illinois, in terms of species extirpations, is severe, it pales in comparison to losses in other groups, most notably freshwater mussels and stoneflies. We are fortunate to have retained nearly 90% of our original nongame vertebrate diversity. In addition, there have been several successful re-introductions and a few species have re-invaded or increased in abundance as a result of habitat restorations. While the majority of the extirpated species of nongame vertebrates were probably never abundant in Illinois (e.g., Alligator Snapping Turtle, American Marten), it is the extirpation (or near-extirpation) of several formerly super-abundant species, such as the Passenger Pigeon and the American Beaver that shows the true potential of man's impacts. This same potential, and how it is harnessed, will determine the fate of this important group in the future.

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CHAPTER 7

Terrestrial Insects: A Hidden Biodiversity Crisis?

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Illinois Natural History Survey

OBJECTIVES

Like most other elements of the biota, the terrestrial insect fauna of Illinois has undergone drastic change since European colonization of the state. Although data are sparse or entirely lacking for most species, it is clear that many formerly abundant native species are now exceedingly rare while a few previously uncommon or undocumented species, both native and exotic, are now abundant. Much of this change may be attributable to fragmentation and loss of native habitats (e.g., deforestation, draining of wetlands, agricultural conversion and intensification, urbanization), although other factors such as invasion by exotic species (including plants, insects and pathogens), misuse of pesticides, and improper management of native ecosystems have probably also been involved. Data from Illinois and elsewhere in the north temperate zone provide evidence that at least some groups of terrestrial insects have undergone dramatic declines over the past several decades, suggesting that insects are no less vulnerable to anthropogenic environmental change than other groups of organisms. Yet, insects continue to be under-represented on official lists of threatened or endangered species and conservation programs focus primarily on vertebrates and plants. This chapter summarizes available information on long-term changes in the terrestrial insect fauna of Illinois, reviews possible causes for these changes, highlights some urgent research needs, and provides recommendations for conservation and management of terrestrial insect communities.

INTRODUCTION

Insects are among the most important "little things that run the world" (1). They comprise approximately 55% of known species (Fig. 7.1) and many are regarded as "ecosystem engineers" due to their influence on vegetation structure and nutrient availability (2). The ecological services provided by terrestrial insects, which include nutrient cycling and pollination, were recently valued at more than $50 billion to the U.S. economy annually (3). On the other hand, certain insect species in their roles as agricultural pests and vectors of animal and plant pathogens are capable of inflicting severe economic losses on human society. Insect herbivores are estimated to reduce crop yields by 18% on average worldwide (4). As early as 1861, Benjamin Walsh (later to become Illinois' first State Entomologist; Fig. 7.2) estimated the annual losses due to injurious insects in Illinois at not less than $20 million (ca. $433 million in today's dollars) and, if one takes into account the losses as well as the costs of pest management, the costs to human society are much higher today.

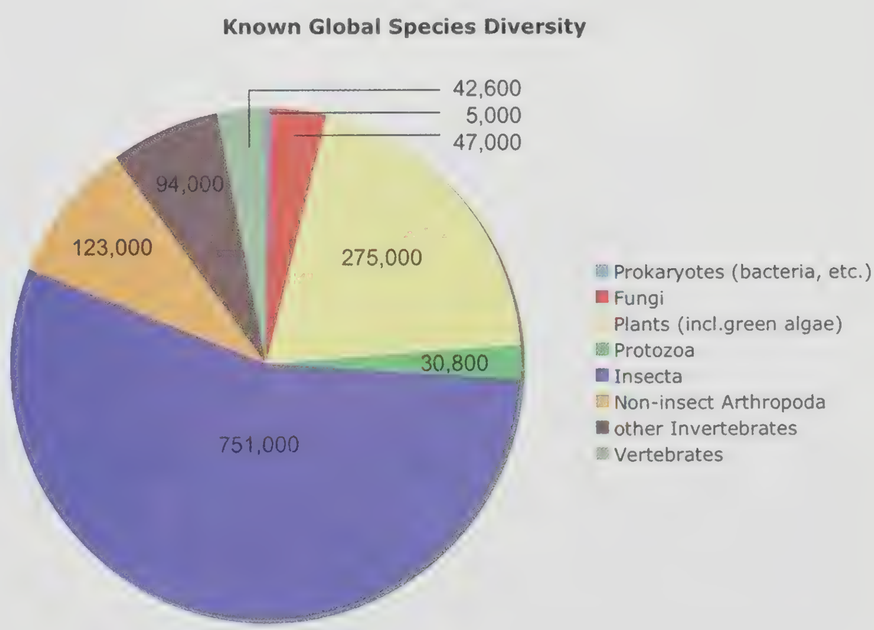

Figure 7.1. Pie chart showing proportion of known species represented by different major groups of organisms based on data from Wilson (80).

Because of their diversity and richness in species and functional groups (including herbivores, detritivores, predators, and parasites) and sensitivity to various kinds of environmental change, insects are useful indicators of both biodiversity and ecological integrity. This has long been recognized for aquatic insects, which are routinely used as bioindicators of water quality (see Chapter 10), but insects are also increasingly being used as indicators of biodiversity and ecological integrity in terrestrial ecosystems (5). Nevertheless, criteria for characterizing natural areas and selecting priority areas for conservation continue to focus almost entirely on vascular plants and vertebrate animals (6), and monitoring of terrestrial ecosystem health traditionally

Figure 7.2. Benjamin D. Walsh (1808–1869), Illinois' first State Entomologist, was the first professional entomologist to attempt to document the insect fauna of Illinois, and one of the first to estimate the economic costs of insect pests. Unfortunately, his insect collection was destroyed in the 1871 Chicago Fire.

has focused mostly on these groups of organisms (7). Terrestrial insect communities are more difficult to monitor because insects are less conspicuous, may be difficult to identify, and their populations may fluctuate dramatically from year to year (8). On the other hand, because insects are the most diverse components of terrestrial ecosystems and often respond rapidly to environmental change, they provide more detailed information than other, less speciose, groups (9). Their responses to disturbance, including common vegetation management practices, may also be quite different from those of plants or vertebrate animals. Use of terrestrial insects as indicators requires detailed knowledge of their distributions and life histories, and acquiring such knowledge has been a major focus of Illinois Natural History Survey (INHS) entomologists over the past 150 years.

Unfortunately, despite their ecological and economic importance, knowledge of terrestrial insects remains fragmentary. At the most basic level, we do not have a precise estimate of the number of species either worldwide (realistic estimates range from 2 to 10 million) or in Illinois. By some estimates, fewer than 10% of insect species extant worldwide have been described and named and species new to science continue to be discovered, even in relatively well-studied regions like Illinois. Even for most named species, the extent of our knowledge is embodied by a few museum specimens, the associated data labels recording the place and date of collection, and a published description of the morphological features distinguishing them from related species. Little or nothing is known about the ecological associations of the vast majority of species. For some insect groups, this is nearly as true for Illinois as it is for the relatively unexplored regions of the tropics.

Available data indicate that at least 33,000 species of insects inhabited Illinois just prior to European settlement (10 and unpublished data), but by the time the insect fauna began to be documented in earnest in the mid-1800s, the landscape of Illinois had already been altered dramatically (see Chapters 4 and 5). Studies of recent fossil insect faunas indicate that the effects of agricultural conversion of the upper Midwest following European colonization were indeed dramatic (11). However, given the extreme paucity of fossil evidence and the mostly nonrandom, opportunistic means by which knowledge of the extant fauna has been assembled, the gaps in our knowledge of the species composition and long-term trends in the Illinois fauna remain large. Nevertheless, the few detailed studies that have been published as well as anecdotal reports and unpublished data provide valuable clues regarding the changes that have occurred over the past 150 years.

ENVIRONMENTAL CHANGES INFLUENCING TERRESTRIAL INSECT FAUNAS

AGRICULTURE.

Since at least the late-1800s, most of the land area of Illinois has been devoted to agriculture. Thus, although influence of other processes such as urbanization and invasions by exotic species should not be discounted, shifting agricultural practices have been the predominant force influencing terrestrial insect communities in the state for more than 100 years. The most detailed and reliable data on long-term trends in populations of Illinois insects are found in the vast economic entomological literature, but this literature has focused almost entirely on insect pests and, to a lesser extent, their natural enemies, which make up <1% of the known species. Entomologists, amateur naturalists, and lay persons alike have published observations of trends in populations of agricultural pests like the Chinch Bug and Armyworm (Fig. 7.3) dating back to the early 1800s. Citing such reports, Decker (12) provided an overview of changes associated with shifting agricultural practices in Illinois from the early 1800s to the 1950s:

> "Before extensive agricultural development of the state, a large part of Illinois consisted of broad expanses of prairie grass, much of which was replaced by timothy and other tame [exotic] grass or cereal crops planted by farmers. Insects preferring these crops became notorious pests, but as the acreage of grasses was reduced as a result of increased legume production, certain insects began to decline in importance. These included the white grubs, the billbugs, the armyworms, the sod webworms, and the corn root aphid. The burrowing webworm and the cutworm…have all but disappeared… As the rail fence was replaced by the wire fence, and roadsides and ditch banks were graded or otherwise cleaned up, the amount of giant ragweed and elderberry available to insects was greatly reduced, so that the common stalk borer

became less important and the old spindleworm was practically exterminated. Likewise, as the pot holes and low spots were drained, wireworm damage in those areas declined steadily. Conversely, in certain dry, sandy areas which were brought under irrigation wireworm damage increased."

Decker's description mentions only a few economically important species, but the dramatic physical alterations to the Illinois landscape he describes presumably affected many nonpest insect species as well.

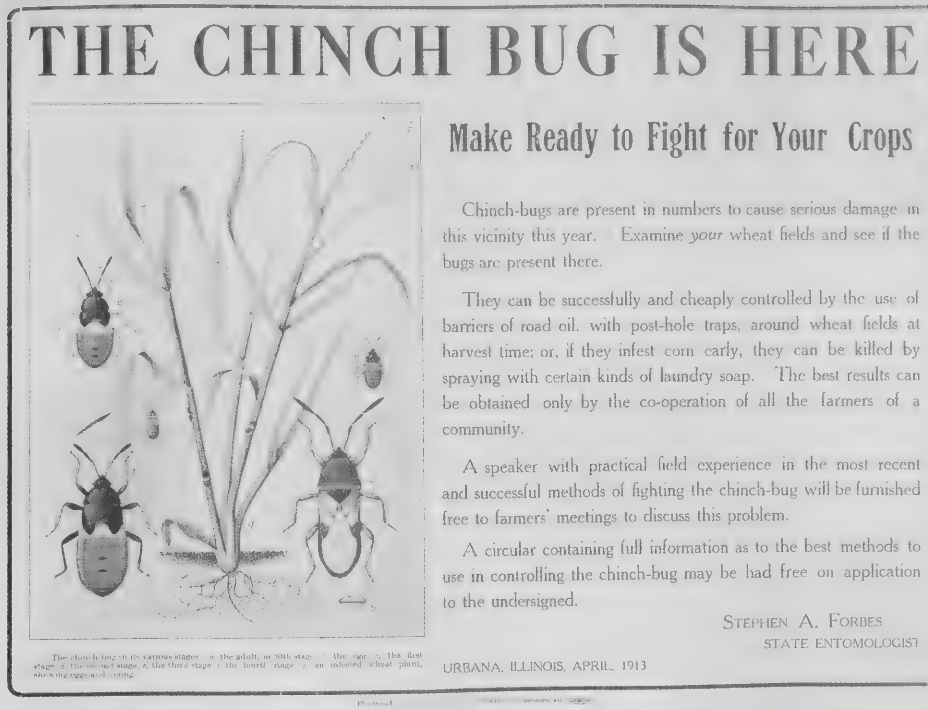

Figure 7.3. Poster circulated by State Entomologist Stephen Forbes in 1913 warning of an outbreak of the Chinch Bug (*Blissus leucopterus*), an insect pest for which detailed records on Illinois outbreaks are available from the mid-1800s.

Changes in the Illinois landscape since the 1950s have been at least as dramatic as those described by Decker (12) for the preceding 100 years, particularly involving expanded production of row crops and dramatic increases in mechanical disturbance of soil and inputs of inorganic fertilizers (13). Such changes, coupled with rapidly evolving strategies for managing agricultural pests (14), have undoubtedly affected terrestrial insect communities. Unfortunately, efforts to document these effects have focused on economically important pest species rather than on the insect community as a whole.

In the years following World War II, inexpensive and highly effective synthetic insecticides were widely adopted for control of crop pests (Fig. 7.4). Compared to earlier inorganic insecticides such as lead arsenate and Paris green, which were highly toxic to humans and plants, and plant-derived insecticidal compounds (e.g., nicotine, pyrethrin, rotenone) which were expensive and lacked residual properties, the new organochlorine compounds like DDT were miraculous. Unfortunately, some insects quickly developed resistance to these insecticides and an arms race ensued, with economic entomologists and insecticide manufacturers on one side and rapidly evolving insect pests on the other. Detrimental effects of DDT and related insecticides on non-target insects were widely documented during the peak years of their use from the mid-1940s to the early 1960s (15), but it was not until Rachel Carson's 1962 bestseller *Silent Spring* publicized links between dramatic declines in populations of birds (and other charismatic organisms) and DDT that serious steps were taken to mitigate these effects. Creation of the U.S. Environmental Protection Agency (EPA) and new restrictions on the use of DDT and some related environmentally persistent insecticides in the early 1970s had dramatic positive impacts on wildlife including, most famously, Bald Eagles. Native insect communities undoubtedly benefitted as well, but data

Figure 7.4. Insecticide sprayer designed by INHS entomologists and used to control European Corn Borer (*Ostrinia nubilalis*) in sweet corn, ca. 1943.

documenting the effects of the DDT ban on nontarget insect communities are lacking. Despite bans of some of the most environmentally persistent chemicals and increased advocacy of science-based integrated pest management strategies (IPM), total use of insecticides in U.S. agroecosystems continued to increase steadily until the late 1990s after which the introduction of genetically modified insect resistant crops (particularly *Bt* corn and cotton) yielded modest reductions in total insecticide applications (Fig. 7.5; 16).

Introduction in the late 1990s of transgenic crops, mostly engineered for insect resistance or herbicide tolerance, has generated much controversy with some authors heralding their potential environmental benefits (17) and others warning of an impending "second silent spring" (18). The potential risks associated with genetically modified organisms (GMOs), including direct or indirect impacts on terrestrial insect communities, have long been recognized (19). Although short-term toxic effects of the most widely planted insect resistant transgenic crops (e.g., corn and cotton engineered to express selected proteins derived from the bacterium *Bacillus thuringiensis*) appear to be negligible in most cases examined, a few studies have shown that these plants are indeed toxic to some nontarget organisms, including predators and parasitoids (20). Nevertheless, such crops generally require fewer applications of conventional insecticides (16) and thus, proponents of GMO crops argue that this will benefit nontarget insects, including pollinators and natural enemies of insect pests (17). Evidence accumulated so far suggests that this is indeed the case, at least in the *Bt*-corn and cotton systems that have been studied most thoroughly, although fields free from GMO crops as well as conventional insecticides continue to support higher diversity and abundance of nontarget organisms (21).

Widespread adoption of herbicide-resistant crops may also affect insect diversity by reducing plant diversity in agroecosystems (22). Clearly, much more research and monitoring will be needed to assess the longer-term impacts of transgenic crops on the terrestrial insect fauna. Biotech corn made up 35% of the total U.S. corn acreage in 2005 and this percentage is likely to increase in the coming years due to the advent of variant Western Corn Rootworms resistant to crop rotation (23). The potential impacts of these changes on insect communities could be dramatic and need to be monitored.

Trends over the past few decades toward the development of less environmentally persistent pesticides, greater reliance on IPM, and increased consumer demand for organic food products would seem to bode well for the conservation of insect biodiversity in agroecosystems. Unfortunately, the positive impacts of such changes may be overwhelmed by an overall trend towards increasing industrialization and homogenization of agriculture, which has resulted in larger farms with less crop diversity and, in some dominant cropping systems, even heavier inputs of chemical fertilizers and pesticides (Fig. 7.5; 16). According to the USDA's National Agricultural Statistics Service, the number of farms in Illinois decreased by 18% between 1987 and 2002 (years for which on-line data are available) while the average farm size increased by 14%. During that same period, the total amount of Illinois land in farms decreased by 4.3%, mostly due to urbanization, but the total acreage devoted to the two dominant crops (corn and soybeans) increased, and insecticide use in both crops also increased, continuing trends toward lower agricultural diversity previously documented for the period 1950–1990 (13).

EXOTIC SPECIES

Since European colonization began, approximately 2,500 exotic species of insects have become established in the continental United States and more than 400 of these are considered pests (Fig. 7.6; 24). Exotic insects that are human disease vectors such as the Asian Tiger Mosquito (*Aedes albopictus*; Fig. 7.6E; 25) or agricultural pests such as the Soybean Aphid (*Aphis glycines*; Fig. 7.6B; 26), both established in Illinois within the past 15 years, make headlines when they are discovered because of their potential impacts on human society. Pimentel et al. (27) estimated the annual costs of such species to the U.S. economy at $20 billion. Remarkably little is known about the impacts of exotic insect species on native insect communities.

Numerous insect species have been introduced intentionally to pollinate crops (e.g., the European Honeybee, Fig. 7.7C), and to control plant pests (e.g., various species of parasitic wasps, Fig. 7.7B) or exotic weeds (e.g., Purple Loosetrife-feeding leaf beetles, Fig.7.7A). According to the USDA Releases of Beneficial Organisms (ROBO) database (28), 187 intentional releases of 9 different species occurred in Illinois during one 5-year period

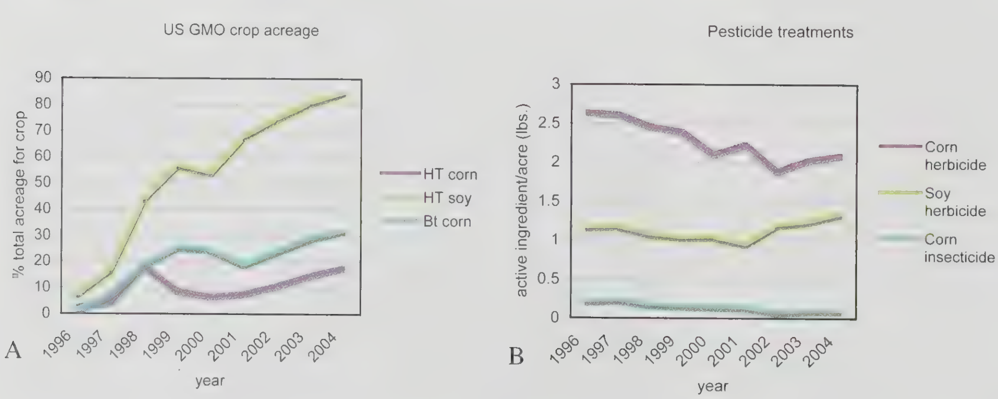

Figure 7.5. Trends in U.S. transgenic (GMO) crops since their introduction in 1996, including herbicide-tolerant (HT) corn and soybean, and corn engineered to express an insecticidal toxin from the bacterium Bacillus thuringiensis (Bt). A, U.S. acreage of transgenic corn and soybean has increased dramatically, particularly for herbicide-tolerant (HT) soybeans, which by 2004 accounted for more than 90% of soybean acres planted. B, As transgenic crops became more prevalent, total use of pesticides declined initially, but use of herbicides in both corn and soybean began to increase in 2002 due to increasing herbicide resistance in some weeds (data from 16).

Figure 7.6. Some exotic insect pests established in Illinois during the past 50 years. A, Gypsy Moth (photo, USDA-APHIS); B, Soybean Aphid (photo by D. Voegtlin); C, Emerald Ash Borer (photo by D. Cappaert); D, Western Corn Rootworm (photo by F. Peairs); E, Asian Tiger Mosquito (photo by S. Ellis); F, Asian Multicolored Lady Beetle (photo by S. Bauer).

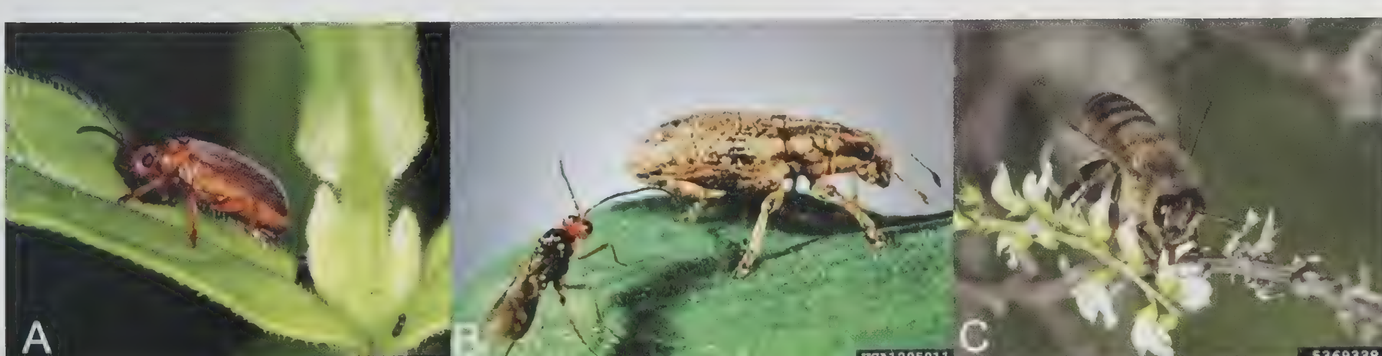

Figure 7.7 Beneficial insects intentionally released into Illinois. A, *Galerucella calmariensis*, a Eurasian leaf beetle introduced for biological control of Purple Loosestrife (photo by D. Cappaert); B, *Microctonus* sp. (lower left), a parasitoid of the Alfalfa Weevil (upper right; photo, by M. McNeill); C, European Honeybee (photo by S. Ellis).

alone (1981–1985, the most recent dates for which data are available on-line). Some exotic species initially thought to be beneficial have become problematic. The Gypsy Moth (Fig. 7.6A), brought to New England from Europe in an attempt to establish a domestic silk industry in the late 1800s, is now the most devastating forest pest in the northeastern U.S. (29). A more recent invader, the Multicolored Asian Lady Beetle (Fig. 7.6F), introduced to control aphid pests of orchards, feeds on a wide variety of non-pest aphids (30), may out-compete native lady beetles (31), invades buildings in large numbers causing a nuisance to homeowners (32), and damages autumn ripening fruits (33). Two exotic European weevils (*Rhinocyllus conicus* and *Larinus planus*) released in the U.S. for biological control of exotic European thistles (e.g., *Carduus nutans* L.), have been shown to reduce seed set in a variety of native thistles (34). In Illinois, non-target "spillover" effects (feeding on plants other than the target weed) of two exotic chrysomelid beetles (*Galerucella* spp.) introduced for biocontrol of Purple Loosestrife (*Lythrum salicaria* L.) have been noted, but so far appear to be short lived (35). Some exotic parasitoids introduced for biocontrol of exotic insect herbivores have also been shown to have significant nontarget effects on native herbivore species (36) and to displace native parasitoid species (e.g., 37). Most cases of intentionally released species becoming problematic are attributable to improper initial screening, and problems seem to have occurred in only a small minority of recent cases, but the longer-term effects of many such introductions remain to be determined.

The majority of exotic insect species introduced into Illinois have arrived here by accident, and because most appear not to have had obvious negative economic or aesthetic impacts, they have largely been ignored. Many exotic herbivores appear to prefer their equally exotic host plants. Examples include the European leafhoppers *Aphrodes bicincta, Arthaldeus pascuellus, Athysanus argentarius*, and *Doratura stylata* (Fig. 7.8C), which prefer non-native cool-season perennial grasses (e.g., *Bromus* spp.). These species, none of which were documented in Illinois by DeLong (Table 7.1; 38) and therefore presumably have become established since the 1940s, are now among the most common insects in Illinois because their non-native host grasses dominate our roadsides, pastures, and lawns. Although the direct impacts of such species on our native

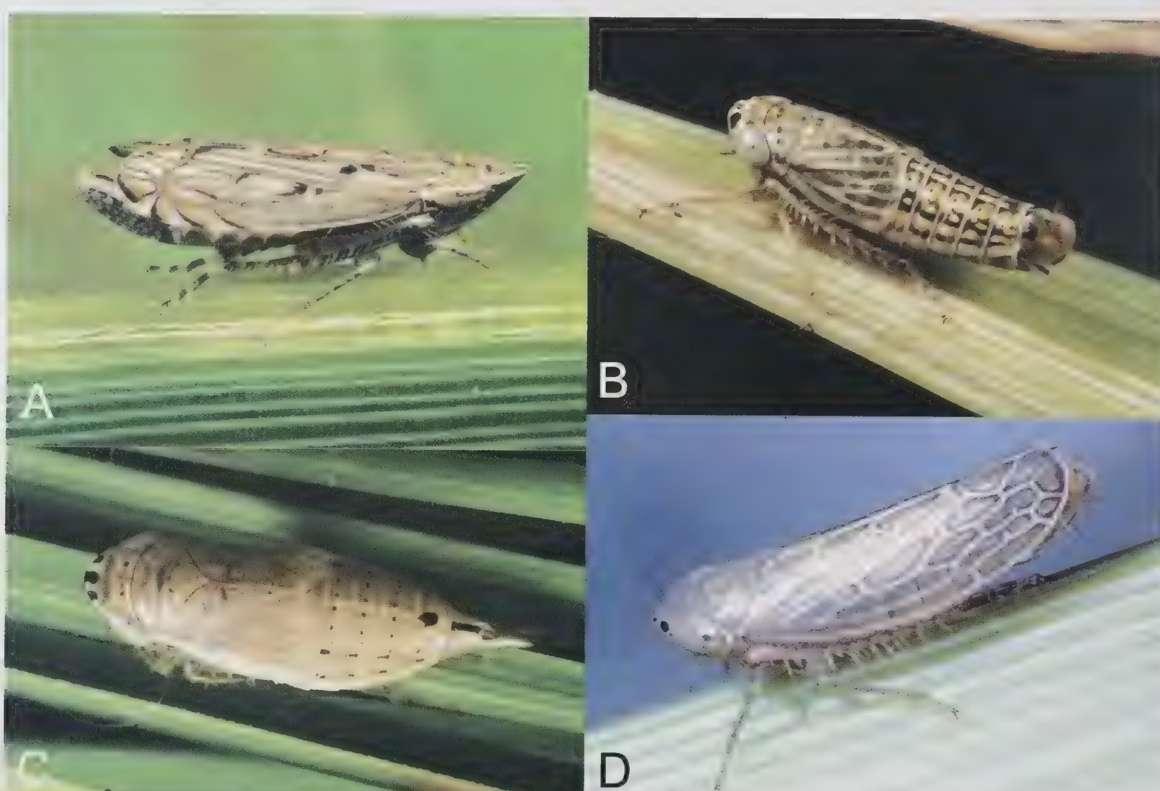

Figure 7.8. Some Illinois grassland leafhoppers. A, *Flexamia atlantica*, a switchgrass-feeding member of a genus that includes several species that are restricted to remnant prairies in Illinois and specialize on native perennial prairie grasses. B, *Athysanella incongrua*, a flightless prairie leafhopper recorded in Illinois only from Revis Hill Prairie, Mason County Another species of the genus, *A. balli*, also appears to be restricted to a single locality in Illinois. *Athysanella acuticauda*, once common in northern Illinois, now appears to be extinct within the state. C, *Doratura stylata*, one of at least seven Eurasian leafhopper species that have become established in Illinois since 1945 (see Table 7.1). This species is now abundant on roadsides, pastures, and prairies where its non-native cool-season grass hosts occur. D, *Kansendria kansiensis* (Tuthill), a species native to the tall-grass prairie of Oklahoma and Kansas, but not recorded in Illinois until the mid-1990s. On isolated prairie remnants in Illinois, this species, which prefers prairie grasses such as Big Bluestem, Little Bluestem, and Indian Grass, appears to be replacing more conservative *Flexamia* species that specialize on these same grasses. Photos by C. Dietrich.

Table 7.1. Eurasian leafhopper (Hemiptera: Cicadellidae) species recorded in Illinois since 1995 that were not found during an extensive survey of the Cicadellidae of the state conducted from 1934–1945 (38).

Anoscopus flavostriatus (Donovan)
Anoscopus serratulae (Fabricius)
Aphrodes bicincta (Schrank)
Athysanus argentarius Metcalf
Arthaldeus pascuellus (Fallén)
Doratura stylata (Boheman)
Paramesus major (Haupt)

biota appear to be minimal, the indirect and longer-term impacts need to be studied. For example, although most non-native leafhoppers do not compete directly with native species for food, they may still indirectly affect native leafhopper populations by providing large reservoirs for populations of predators, parasitoids, and pathogens that may attack native and non-native leafhoppers alike.

From the standpoint of biodiversity conservation, exotic species that invade native ecosystems are of greater concern than those that confine themselves to human-altered landscapes (see Chapter 12). Exotic generalist herbivores such as the Gypsy Moth (Fig. 7.6A), Japanese Beetle, and Asian Longhorned Beetle, as well as more host-specific but equally destructive species like the Emerald Ash Borer (Fig. 7.6C) are able to wreak havoc on forest ecosystems because they overwhelm potential natural enemies and/or the defenses of plants upon which they feed. Such species may displace native insects directly through competition, or indirectly through their roles as "ecosystem engineers" whose impacts cascade through the community, affecting many other species (2).

Exotic plants, which dominate today's Illinois landscape, have probably affected native insect communities to an even greater degree than exotic insects, but such effects have scarcely been documented. Although data on the pre-settlement insect biota are scarce, replacement of virtually all the native prairie and much of the native forest and wetland by monocultures of corn and soybean (both exotic species), non-native cool season grass pastures, and suburban lawns, and invasion of many natural areas by exotic weeds such as Garlic Mustard and Purple Loosestrife, have been accompanied by reductions in insect biodiversity over much of the state (see below). Because the vast majority of native insect herbivores specialize on only a few species, genera, or families of plants, they are not able to persist in such anthropogenic ecosystems because suitable host plants are absent. Faunas of predators, parasitoids, and detritivores in such systems also tend to be relatively depauperate compared to native ecosystems (39).

RESPONSES OF NATIVE INSECT COMMUNITIES

The effects of anthropogenic environmental changes, such as those described above on terrestrial insect communities, are not well documented. Impacts of agricultural intensification have been studied extensively in Europe (40) but most such studies have focused on insects only because of their importance as food for birds, and few have considered insect communities and species in their own right. In the absence of explicit long-term monitoring programs, data must be gleaned from other sources, such as insect collections and the few studies in which the same areas have been sampled repeatedly over time. Cause-effect relationships among any of the above mentioned environmental changes and changes in terrestrial insect communities remain largely speculative, but given sufficient data, appropriate analytical methods are available (41).

Since the 1850s, extensive field work throughout Illinois, often associated with surveys of insect pests, has yielded the wealth of specimens of all terrestrial insect groups now housed in the collections of the Illinois Natural History Survey (ca. 7 million specimens) and other institutions (Fig. 7.9). Unfortunately, efforts to synthesize the information embodied in those collections have been relatively modest. Since 1900, numerous monographs and checklists, many authored by INHS entomologists, have been published, focusing largely or entirely on the terrestrial insects of Illinois (Table 7.2). Collectively, these works comprise approximately 3,800 species and, thus, represent <12% of the insect fauna of the state. Information on additional species in certain groups may be found in more comprehensive works on the fauna of North America (e.g., 42, 43), although few such works include details on species distributions within Illinois. In addition to the several taxonomic and faunistic works produced by professional entomologists, some notable contributions have been made by amateurs collecting over many years in their local areas (Fig. 7.10). These include Charles Robertson's list of insects visiting flowers in the Carlinville area, compiled over a 30-year period beginning in 1884 (44), and Murray Glenn's collections of microlepidoptera (small moths) between 1927 and 1976 from the area near the confluence of Sandy Creek and the Illinois River in Putnam and Marshall counties (45). Such compilations, which have facilitated more recent analyses of host specificity (46, 47) and community composition (48) are, unfortunately, very rare and few are accompanied by collections of voucher specimens.

Table 7.2. Partial list of publications documenting the Illinois terrestrial insect fauna.

Insect group	Citation
Stink bugs	(84)
Aphids	(85)
Grasshoppers, Earwigs, and relatives	(86)
Plant bugs	(87)
Leafhoppers	(38)
Thrips	(88)
Butterflies	(89)
Scorpionflies	(90)
True bugs	(91, 92, 93)
Planthoppers	(94)
Horse flies	(95)
Butterflies	(96)
Silk moths	(97)
Skippers	(98)

Figure 7.9. View of one section of the compactor containing a portion of the INHS insect collection.

Although some published resources provide invaluable summaries (with varying degrees of detail) of the known distributions of terrestrial insect species, and often include notes on the ecological associations and relative abundance of the included species, they provide few details on temporal trends in diversity or abundance. Because most insect species cannot be readily identified in the field, sight records are usually deemed reliable for only a few groups of larger, more distinctive species (e.g., butterflies and dragonflies). Data that would facilitate analysis of population trends in most groups of insects are either unavailable or not readily accessible because they are confined to specimen labels in insect collections. Efforts to enter such data into electronic databases have been underway for nearly 20 years, but at present rates of data entry it will take decades to digitize all relevant specimen records in the INHS collection alone.

Few studies have so far explicitly attempted to detect trends or long-term changes in Illinois terrestrial insect communities. Kendiegh (8) summarized the results of a long-term monitoring study of invertebrates in three University of Illinois-owned wood lots sampled yearly for periods of up to 35 years (1935–1970). He found that abundances of several common insect species tended to fluctuate dramatically from year to year and that environmental variables such as rainfall and winter temperature were good predictors of these fluctuations. This study detected no consistent long-term trends in most taxa studied. The dramatic year to year fluctuations in abundance seen in most groups monitored by Kendeigh accentuates the need for long-term monitoring to discern real trends in terrestrial insect communities.

In the early 1970s, Marlin and LaBerge (48) re-sampled native bees in the vicinity of Carlinville in west-central Ilinois, an area that had been surveyed extensively over a 30-year period beginning in the late 1800s (44). They found that 140 of the 171 bee species (82%) previously documented on the 24 flowering plant species considered in their study were still present in the Carlinville area, and also found an additional 14 native bee species not collected by Robertson. Marlin and LaBerge concluded that the native bee community was largely intact, despite the considerable habitat fragmentation that occurred in the Carlinville area during the previous 80 years. Recent studies conducted elsewhere in the northern hemisphere have also tended to show that native bee communities respond more to habitat quality (i.e., native plant diversity) than to patch size (Fig. 7.11) or degree of isolation (49) and that this pattern may be generally applicable to highly mobile insect species (50).

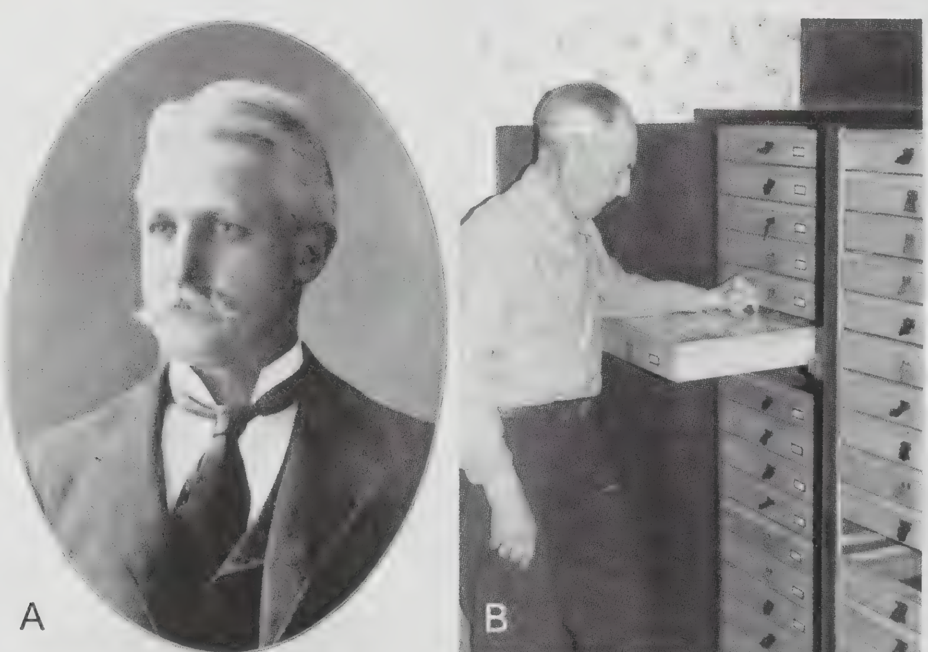

Figure 7.10. Pioneering amateur Illinois entomologists. A, Charles Robertson (1858–1935), a botany professor at Blackburn College, Carlinville, whose collection of bees and other flower-visiting insects, assembled over a 30 year period beginning in 1884 (housed at INHS), has provided the basis for recent studies on host specificity and the effects of land-use change on bee communities. B, Murray Glenn (1893–1981), a farmer and amateur lepidopterist, with his collection of ca. 30,000 meticulously prepared microlepidoptera specimens, representing 954 species, accumulated between 1927 and 1976 and donated to the INHS.

Figure 7.11. Habitat fragmentation, such as the forest pictured here, is a major factor contributing to the loss of the biodiversity of insects and other organisms across Illinois and the Midwest. Photo by M. Jeffords.

Other evidence indicates that the rarest insect species, many of which are associated with prairies, are indeed faring poorly. Approximately 20% of the prairie and savanna-inhabiting butterflies of Illinois have been nominated for listing as threatened or endangered species (54, Fig. 7.12). Species already listed include the federally endangered Karner Blue Butterfly, and the state-listed Ottoe and Arogos Skippers, all of which may have been extirpated from Illinois. Lesser known groups such as leafhoppers, many species of which are associated with prairie, have experienced similar losses. The leafhopper species *Attenuipyga vanduzeei, Athysanella acuticauda, Hebecephalus signatifrons, Laevicephalus pravus,* and *Paraphlepsius lupalus,* all or most of which are specialists on prairie grasses, and all previously recorded from northern Illinois, may be extinct within the state. Several other prairie leafhopper species, including *Athysanella balli, A. incongrua* (Fig. 7.8B), *Commelus colon, Cuerna alpina, Flexamia grammica,* and *Mesamia straminea* are known from single localities; and most of the approximately 100 other prairie-specialist leafhoppers and planthoppers recorded from Illinois are known from 5 or fewer localities. According to DeLong (38) some of these species (e.g., *Flexamia prairiana, Laevicephalus unicoloraus, Graminella aureovittata*) were "common" or "abundant" in Illinois during the 1930s and 40s when the most thorough inventory of Illinois leafhoppers took place.

In the most detailed assessment of the conservation status of Illinois insects to date, Panzer and colleagues (51, 52) sampled insects intensively in prairie and non-prairie habitats over a 12-year period (1982–1994) in the Chicago metropolitan area of northern Illinois, southern Wisconsin, and northwestern Indiana. They targeted relatively well-studied insect taxa, emphasizing groups of herbivores thought most likely to include ecologically conservative (remnant-dependent) species based on known life-history characteristics (e.g., specialization on prairie plants, flightlessness). Although the main goals of their study were to determine the degree of remnant dependance of selected insect taxa and examine the effects of prescribed burning on prairie insects, the study also provided insights into the degree to which prairie- and savanna-inhabiting insect communities in Illinois have changed over the past century. Of the 1,100 species in their focal taxa previously recorded from the Chicago area, they were unable to find 143 (13%). Among the species sampled, they classified 256 (ca. 27%) as remnant-dependent due to their apparent restriction to remnant patches of native prairie or savanna vegetation. The remaining species were deemed remnant-independent because of their presence in various anthropogenic habitats including old fields, pastures, and rights-of-way. Although the data provided by Panzer et al. indicate that a majority of the considered species recorded historically continued to persist in the Chicago region in the 1980s and early 1990s, many of the remnant-dependent species are now extremely rare or absent. Because >90% of the insect species considered in their study occupy a single trophic level (herbivores), the results may not be representative of the status of the terrestrial insect fauna as a whole, which also includes large numbers of predators, parasitoids, fungivores, and detritivores. Also, the results obtained from this study may not be representative of Illinois as a whole because the Chicago region has a disproportionately large share of native prairie and savanna remnants compared to most other parts of the state (53).

Interestingly, populations of one prairie leafhopper, *Kansendria kansiensis* (Fig. 7.8D), seem to be increasing. This species, which feeds on various prairie grasses including Big Bluestem, Indian Grass, and Little Bluestem, was first recorded from, and seems to be native to, the tallgrass prairie of Kansas and Oklahoma. It was not collected in Illinois until the mid 1990s, and in subsequent years it has become much more common. This species, which is fully winged and apparently highly mobile, has recently colonized many remnant and restored prairies throughout Illinois where it seems to replace some of the more conservative, flight-limited, and fire-sensitive *Flexamia* leafhoppers (Dietrich, unpublished). Currently, *Kansendria kansiensis* is included on the Illinois list of species in greatest need of conservation, but its dramatic increases over the past decade suggests that it may eventually need to be re-classified as an invasive species.

A recent survey of insects listed as threatened or endangered in Illinois (7 butterflies/moths (Fig. 7.13), 1 dragonfly, 2 leafhoppers), nearly all of which are associated with prairie, revealed that these species were no longer present at or near 23 of the 33 localities where they had been recorded most recently (Dietrich, unpublished); in most cases the habitat available at the site was no longer suitable for the species. A more extensive survey of 330 insect "species in greatest need of conservation" listed by the Illinois Department of Natural Resources, also mostly comprising

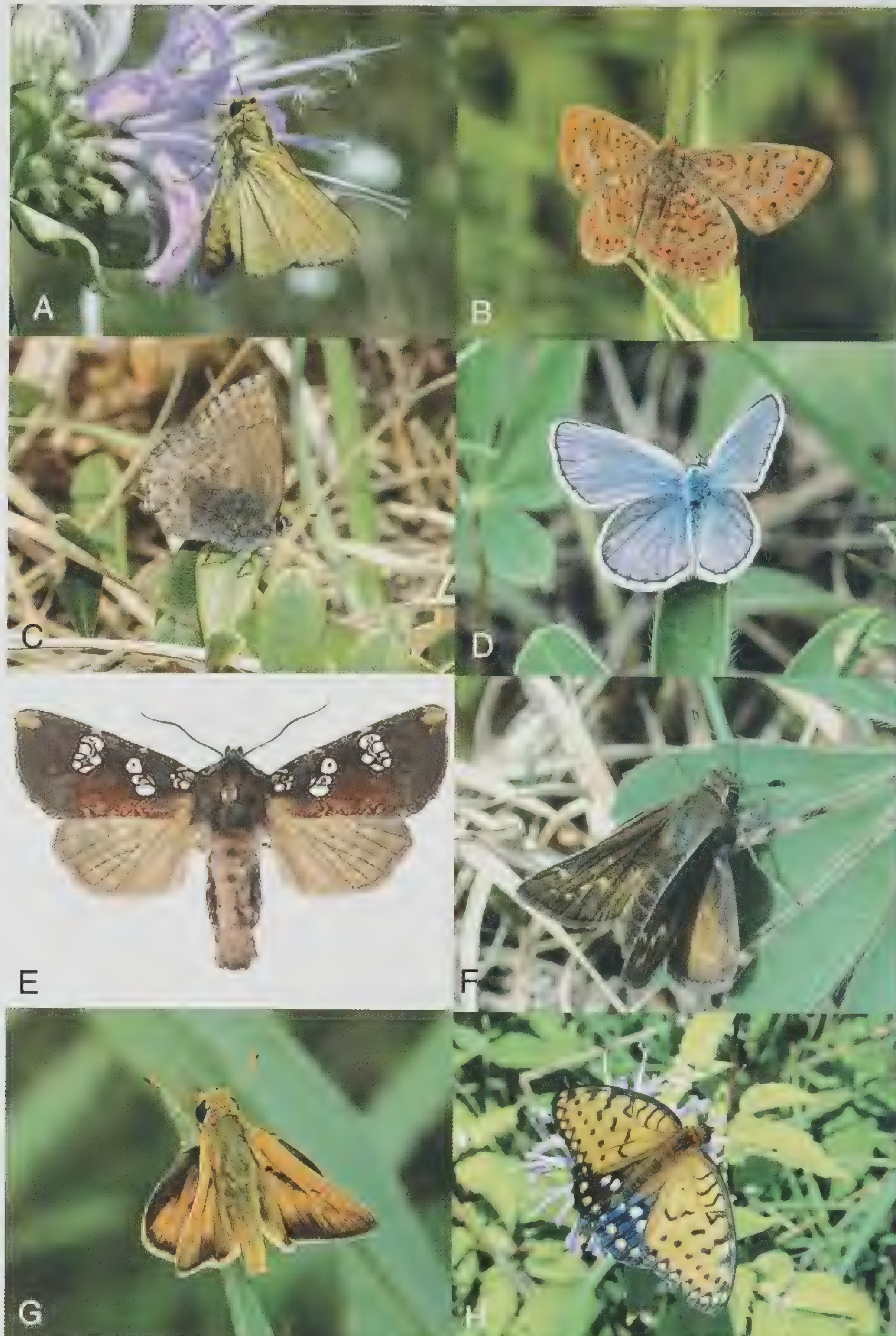

Figure 7.12. Some insects listed as threatened or endangered in Illinois. A, Arogos Skipper; B, Swamp Metalmark; C, Hoary Elfin; D, Karner Blue; E, Eryngium Stem Borer; F, Cobweb Skipper; G, Ottoe Skipper; H, Regal Fritillary. (Photos by M. Reese, wisconsinbutterflies.org, except E by J. Wiker).

Figure 7.13. Suction trap used to monitor spread of the Soybean Aphid (photo by D. Voegtlin).

species associated with prairie, is currently underway and is so far yielding similar results (Dietrich, unpublished).

Figure 7.14. Sweep sampling for insects as part of the Critical Trends Assessment Project (photo courtesy of CTAP).

LONG-TERM MONITORING

Although much information of potential value for examining long-term trends in the terrestrial insect biota of Illinois is available on specimen labels in insect collections, such data are fragmentary at best and reflect the geographic and taxonomic biases of the individual collectors. Repeated quantitative surveys conducted over many years such as those conducted for fishes (see Chapter 9) and birds (see Chapter 6) provide a better means of discerning trends. Unfortunately, efforts to monitor non-pest terrestrial insects on a regular basis have expanded only very recently. The annual Fourth of July Butterfly Counts, begun in the U.S. by the Xerces Society in 1974 have increased steadily in number and currently

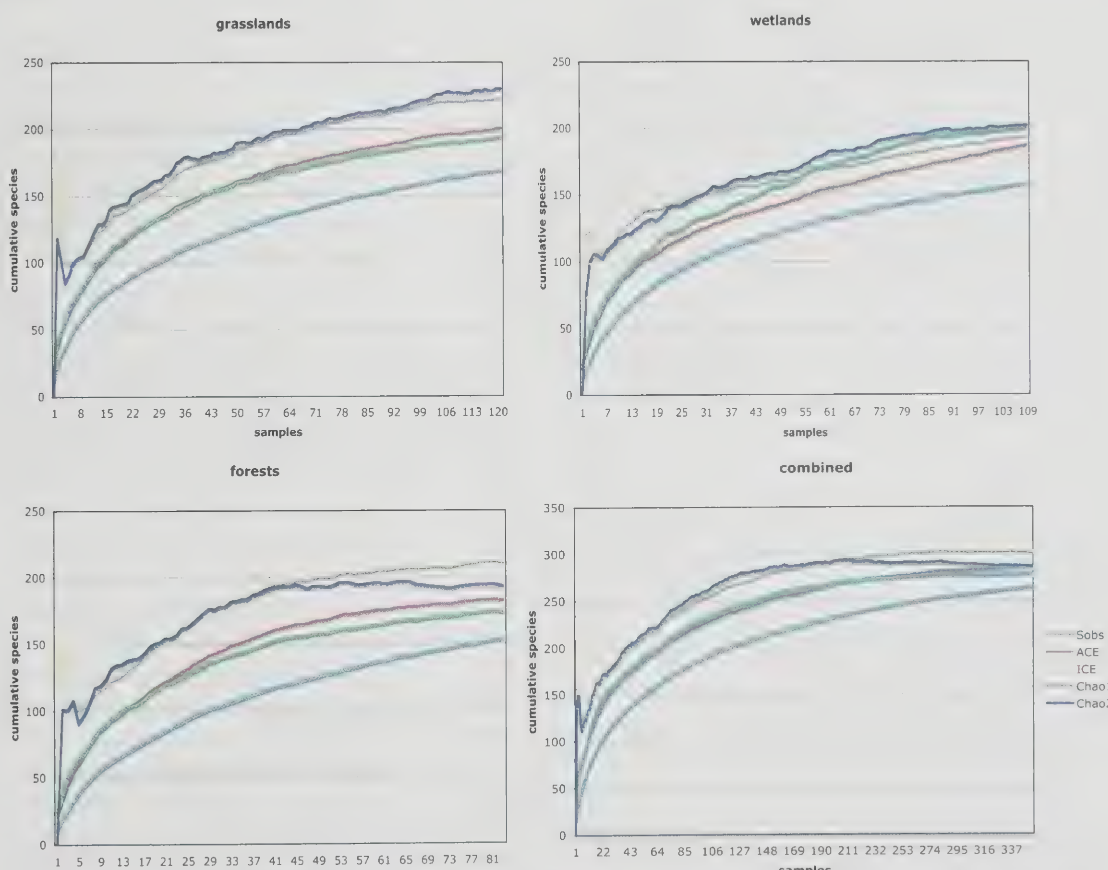

Figure 7.15. Species accumulation curves for leafhoppers, planthoppers and related insects (Auchenorrhyncha) based on data from the first five years (1997–2001) of terrestrial insect sampling associated with the Critical Trends Assessment Program (CTAP). Cumulative species observed (Sobs) are shown along with values for several commonly used non-parametric richness estimators (ACE = Abundance-based Coverage Estimator; ICE = Incidence-based Coverage Estimator; 1 and 2 = richness estimators from Chao (81, 82, respectively; see 83). Separate curves for grasslands, wetlands, and forests did not reach an asymptote, suggesting that additional sampling in these habitats is likely to reveal the presence of more species, but the combined data suggest that additional sweep sampling in "typical" Illinois habitats is likely to reveal no more than approximately 300 species of Auchenorrhyncha.

yield data on butterfly sightings nationwide, including in Illinois. However, their geographic coverage is far from comprehensive and the quality of the data is highly variable, so their usefulness in tracking long-term trends in butterfly numbers remains to be determined (55). A network of nine 25-foot-tall suction traps (Fig. 7.13) distributed throughout Illinois was established in 2001 to monitor the Soybean Aphid (*Aphis glycines*) but has begun to yield a wealth of data on other aphid species (56; Voegtlin and Lagos unpublished).

In 1997, a statewide monitoring program (Critical Trends Assessment Project, CTAP) was initiated in Illinois to document change to the overall biota, including terrestrial insects, using stratified, quantitative, random sampling (see Chapter 15). Terrestrial insects are sampled by sweeping once each year over a 50-meter transect at each site. Because of funding constraints, most insects sampled are sorted only to order and morphospecies (e.g., Coleoptera sp. 1) and species in only one indicator group (auchenorrhynchous Hemiptera—leafhoppers, planthoppers, and relatives) are positively identified to species. Although it is still too early for significant trends to be detected, the data gathered so far paint a rather stark picture of the current state of the native terrestrial insect fauna of Illinois.

In the first five years of CTAP sampling (Fig. 7.14), which covered a total of 354 sites randomly distributed throughout Illinois, 274 Auchenorrhyncha species were collected, representing approximately 22% of the known Auchenorrhyncha fauna of the state (57, 58, 59, and unpublished). Species richness was, on average, slightly higher in grasslands than in forests and wetlands, with only grasslands and wetlands being significantly different. Extrapolations based on species accumulation curves generated from the sample data for grasslands and wetlands (Fig. 7.15) suggest that additional sampling in these habitats is likely to reveal few additional species. Although curves based on CTAP sample data for grasslands, wetlands, and forests each failed to reach an asymptote, the curves for the combined data reached an asymptote and indicate that no more than ca. 300 Auchenorrhyncha species are expected to be found in these habitats using sweep sampling. Sweep sampling is inefficient in forests, so the insect fauna of Illinois forests is undoubtedly much richer in species than documented thus far by CTAP sampling. Nevertheless, considering the data from grasslands and wetlands alone, only 103 of the 346 (29.8%) Illinois Auchenorrhyncha species that are either restricted to, or frequently occur in, these habitats have been encountered in CTAP sampling. If Auchenorrhyncha are representative of terrestrial insects in general, then the CTAP sample data suggest that ca. 70% of the species constituting the original insect fauna have been extirpated from the "typical" (i.e., low quality) grasslands and wetlands in Illinois, a pattern similar to that observed for birds and plants (60, 61). Moreover, insect species inhabiting these habitats, which are now dominated by non-native plants, tend to be less conservative on average than those inhabiting high quality sites. For nearly all sites sampled, conservative Auchenorrhyncha species (host- or habitat specialists and/or flight-limited species) are far outnumbered by nonconservative species (highly mobile habitat and host generalists) and some wetland and grassland sites lack conservative species altogether.

CONSERVING AND RESTORING THE NATIVE BIOTA

Conservation of terrestrial insects in Illinois presents numerous challenges. Agricultural intensification and urbanization continue to fragment the landscape with vast areas now devoid of native vegetation and many natural areas being invaded by exotic species. Applications of pesticides continue to increase steadily in response to introductions of herbicide-resistant crops, invasions of new pests and evolving resistance in old ones (16). Meanwhile, insects as a class continue to be categorized as undesirable and attempts to list "bugs" as endangered species have been used by anti-environmental propagandists to undermine support for the Endangered Species Act and conservation programs in general (62).

Compounding these problems, knowledge of the Illinois insect fauna remains far from complete. For most groups of insects, we still lack a precise accounting of which species occur (or occurred) in Illinois, and native species continue to be discovered here, even in relatively well-studied taxa (43). Because the more widespread, generalist insect species are most likely to be encountered by collectors, the known fauna probably comprises a greater proportion of such species than the unknown fauna. Indeed, most of the native insects newly discovered in Illinois since 1995 appear to be habitat or host specialists (e.g., *Athysanella incongrua*, Fig. 7.8B). Ecological theory predicts that such species are at greatest risk of extinction; thus, management of native insect communities must be undertaken with the assumption that species encountered in general sampling and monitoring programs may not be truly representative of the fauna at large. Likewise, the few well-documented cases of declines and extinctions of better-studied insect species must represent only the tip of the iceberg, with many species being driven to extinction without our even being aware of their existence (63, 64).

MANAGEMENT FOR TERRESTRIAL INSECT CONSERVATION

Management of native ecosystems is usually geared toward preserving native vegetation and/or populations of endangered vertebrate animals. Maintenance of insect biodiversity has often either been an afterthought or ignored altogether, although the necessity of preserving native pollinators has recently received considerable attention (65). It is often assumed that maintenance and/or restoration of habitat will be sufficient to sustain native insect biodiversity, but the validity of this assumption is questionable and available data indicate that insect responses to management are complex and often unpredictable. Because insects are so diverse in their ecological requirements, any disturbance-based management will favor some species and harm others. Thus, it is important for land managers to ensure that the species harmed are not those in greatest

need of conservation. Efforts like those of Panzer et al. (52) to determine which insect species are restricted to remnant prairie and savanna habitats need to be replicated statewide and the taxonomic focus of such studies needs to be expanded beyond the few relatively well-known groups (e.g., butterflies, dragonflies, leafhoppers) considered so far. Large, conspicuous insects like butterflies or those which tend to occur in large numbers, such as certain leafhoppers are the most amenable to monitoring because they are easy to observe, sample, and track using statistically robust methods (66, 67), but it seems unlikely that such groups by themselves are adequate as indicators for the terrestrial insect community at large. The majority of insect species in most habitats tend to be rare and such species should continue to be emphasized in conservation programs, although widespread, generalist species are certainly not immune to population collapse and extinction (e.g., the Rocky Mountain Grasshopper, 68; British large moths, 69). Managers must assume that most of the diversity in terrestrial insect communities is effectively invisible and that declines in the most conspicuous species are indicative of much steeper declines in the less conspicuous species (63).

In highly fragmented ecosystems, enhancing the biodiversity of insect communities appears to be much easier than for plants or birds (70, 71). Because most of Illinois consists of agricultural lands, the potential of conservation incentive programs for enhancing insect biodiversity is tremendous. The European Union has established incentive programs (agri-environment schemes) explicitly geared toward the conservation of biodiversity, and although practices vary considerably among countries, these programs have been shown to improve insect biodiversity overall in intensively managed agroecosystems (72). No comparable programs exist in the United States although the USDA's Conservation Reserve Program (designed to reduce overproduction and remove highly erodable land from cultivation) may have inadvertently benefitted native insect communities. With appropriate enhancements, such programs could provide large areas of restored habitat for native insects and other wildlife (73). However, special efforts, such as increased planting of native perennial host plants and re-introductions of breeding individuals, may be needed to facilitate recovery of the rarest and most specialized insect species when no local source populations exist (74). Adoption of organic farming practices has also been shown to enhance insect biodiversity, particularly in intensively farmed regions (71). Although well-managed agricultural systems may support diverse faunas of terrestrial insects (75), native plant communities of similar size in the same region tend to support far more species (76). Clearly, the best strategy for conserving native insect biodiversity is to prevent the destruction of native habitats in the first place.

RESTORATION

Restoring the insect biota of native Illinois ecosystems will be difficult. Reconstruction and judicious management of native vegetation is an important first step, but many native insects apparently have difficulty re-colonizing reconstructed habitats (74). Prairie reconstructions in Illinois and elsewhere in the Midwest usually have been found to harbor many fewer conservative prairie insects than native remnants of comparable size, despite an abundance of suitable host plants, even many years after they have been established. Reconstructions placed along natural habitat corridors may quickly re-acquire their native arthropod communities, but many reconstructed Illinois prairies separated from the nearest possible source populations by dozens of miles of corn and soybeans, may never recover their native insect faunas without human intervention. Distance from source populations has been shown to be a major factor affecting insect diversity of patches of native or semi-natural vegetation (40); thus it is not surprising that many reconstructions, surrounded on all sides by miles of corn and soybean fields, lack conservative insect species. Attempts to reintroduce native insects into restored habitats have so far met with mixed success (5).

Because knowledge of the composition of the original pre-settlement insect fauna is fragmentary, another important step in restoration of the native insect fauna will be to compile and analyze all the relevant historical collection data. Efforts to do this are underway (see, e.g, INHS Insect Collection database: http://ctap.inhs.uiuc.edu/Insect/search_inhs.asp) but need to be expanded. Even when such data become accessible, for many lesser known groups it will only be possible to make educated guesses about which species belong here.

Clearly the most effective conservation strategy for endangered insect populations is to identify extant populations, protect the land upon which these populations occur, and expand their habitat by acquiring and restoring native vegetation on adjacent areas. Management must not only seek to preserve species that are restricted to native habitats but must also preserve the processes that allow native communities of plants and insects to persist by maintaining diverse assemblages at all trophic levels (77).

MONITORING

Because responses of insect communities to restoration and management efforts may be complex and unpredictable, management must include a monitoring component. Most monitoring programs incorporating terrestrial insects have either focused on single species (e.g., certain endangered butterflies) or have used higher taxa (e.g., families, orders) as surrogates for the insect community at large spacial scales (5). Many studies that have used the latter approach to compare levels of insect diversity among habitat patches under different management regimes within a particular landscape have failed to detect significant management effects on abundance and diversity. In at least some cases this seems to be because, for many diverse insect orders or families, harmful effects of management on some species tend to be balanced by beneficial effects on others (78). Panzer (54) and others have stressed the importance of focusing conservation and monitoring efforts on species that are largely restricted to remnants of native vegetation, as opposed to those capable of surviving in the dominant anthropogenic landscape. However, tracking population trends in all such species is usually not feasible. Thus,

monitoring will need to focus on a limited number of indicator species that are known to be at risk and are at the same time representative of various functional groups. Monitoring should include native as well as non-native species, given the potential of non-native species to become invasive. Improved methods of detecting and tracking the spread of invasive insects are needed.

SUMMARY

The dramatic declines in biodiversity over much of Illinois reported for better studied groups of terrestrial organisms such as birds and vascular plants, brought about largely due to the destruction or fragmentation of native habitats, are almost certainly being paralleled by those of insects and other less conspicuous elements of the Illinois biota. Unfortunately, except for a few species of economically important insects, data on long-term trends in insect populations and the diversity of native insect communities remain extremely sparse. Although extensive surveys of terrestrial insects were conducted by INHS entomologists during the first half of the twentieth century, these surveys have been repeated recently for only a few groups in a few areas. A wealth of additional historical data are also available in insect collections, but at present these data are poorly accessible and underutilized. Thus, the current conservation status of most native Illinois insect species remains unknown. Available data suggest that 13% of the native prairie insects originally inhabiting the Chicago region are now extinct and, because much of the remaining high-quality prairie is concentrated in this region, the situation in other parts of the state may be considerably worse; e.g., the CTAP statewide monitoring program has so far detected <30% of the Auchenorrhyncha species previously recorded from Illinois.

Monitoring terrestrial insect communities is challenging because insects are diverse, difficult to identify, their populations often fluctuate dramatically from year to year, and their responses to management may not parallel those of vascular plants or vertebrate animals. Nevertheless, because insects comprise the single largest component of terrestrial biodiversity, play crucial roles in pollination and nutrient cycling, and are critical food sources for many vertebrate species the conservation of native insect communities is of crucial importance.

During their more than 400 million years on earth, insects have recovered from at least five previous global mass extinctions (79) and they will likely survive the current one. Unfortunately, it is not clear how much insect biodiversity can be lost without seriously compromising the crucial ecosystem services upon which human society depends. Clearly for our own sake we should err on the side of caution. If humanity does not soon heed the accumulating evidence of an unfolding sixth global biodiversity crisis, we may well be among its casualties.

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Chapter 8

Our Ever-changing Wildlife Populations

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OBJECTIVES

In this chapter, selected noteworthy species of game animals and their current population status in Illinois will be discussed along with critical environmental factors affecting their numbers and their future. Much of that discussion is facilitated through the work of the Illinois Natural History Survey, which has maintained an important role in wildlife research and management since the 1930s.

INTRODUCTION

As documented throughout the other chapters of this book, the landscapes of Illinois, the Midwest, and our nation have changed considerably since colonization by the Europeans. Although habitat changes have been ongoing for centuries in our nation, the professional monitoring of wildlife populations only began in earnest during the 1930s. Illinois was blessed with rich soils, productive wetlands and riverine systems, high-quality hardwood forests, and vast expanses of prairie. Concordantly, the size, distribution, and health of wildlife populations are directly dependent upon those very habitat characteristics. As man altered our landscapes either directly through practices including clearing, draining, and development or indirectly through environmental contaminants including pesticides and industrial waste, wildlife populations have changed—some positively and some negatively.

IMPACT OF EUROPEAN SETTLERS AND FARMING IN THE 1800s

The past century and a half has been unprecedented in man's rapid alteration of game species populations and their habitats. The perceptions and use of game animals by Illinois citizens have been in transition as well. From a long-term perspective, the profound changes are rooted in the arrival of European settlers and the gradual emergence of intensive agriculture and highly developed human settlements. By the early 1800s, the presence of European settlers practicing subsistence farming was growing in the Prairie State. At the signing of the Chicago Treaty of 1833, Shabonee, a well-known Potawatomi leader in northern Illinois, lamented with prophetic words the far-reaching implications of these changes:

> *In my youthful days, I have seen large herds of buffalo on these prairies, and elk were found in every grove, but they are here no more, having gone towards the setting sun. For hundreds of miles no white man lived but now trading posts and settlers are found here and there throughout the country, and in a few years the smoke from their cabins will be seen to rise from every grove, and the prairies covered with their cornfield*—(http://www.accessgenealogy.com/native/tribes/pottawatomie/pottawatomiechiefs.htm).

Although anthropogenic habitat changes were important at this time, the first wave of species extinctions came from over-exploitation by Euro-Americans. For example, in approximate order of disappearance, the Elk (*Cervus elaphus*), Bison (*Bison bison*), Black Bear (*Ursus americanus*), Mountain Lion (*Puma concolor*), Fisher (*Martes pennanti*), Gray Wolf (*Canis lupus*), and White-tailed Deer (*Odocoileus virginianus*) faded from Illinois from about 1840 through the years following the Civil War (1) (see Chapter 6).

The first agricultural census, authorized by President Lincoln, indicated that some of the country's most productive and high-priced cropland was in central Illinois. The stage was set for a developing commercial farm economy and wave after wave of agricultural innovations that targeted the most productive and expensive land—the deep, dark prairie soils. As Illinois became an epicenter for intensive farming, habitat conditions for upland game—for better or worse—were affected throughout the state as well as over the Corn Belt and other intensively cropped parts of the continent (Figs. 8.1 and 8.2). Thus, in many ways, the altered habitat conditions created by agriculture in Illinois were a harbinger of things to come elsewhere (2).

ILLINOIS' WATERFOWL HISTORY

Illinois has a rich waterfowl tradition. Few states, if any, have experienced such a multifaceted history. Private duck clubs, some rather grandiose and others quite humble, appeared in the 1880s. Market hunting became a style of life for those attuned to the ways of waterfowl and rivers,

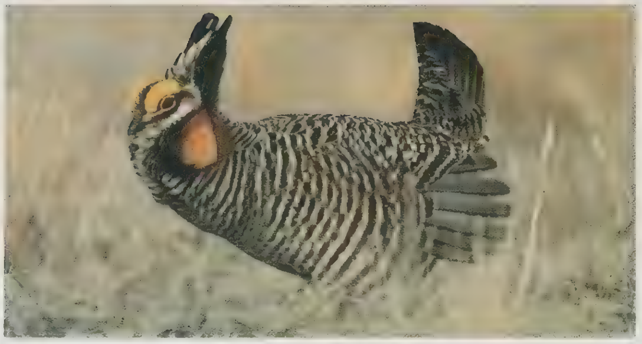

Figure 8.1. Numbers of Greater Prairie Chickens present and harvested in Illinois declined dramatically as cropland replaced native grasses in the late 1800s. Photo by M.K. Rubey.

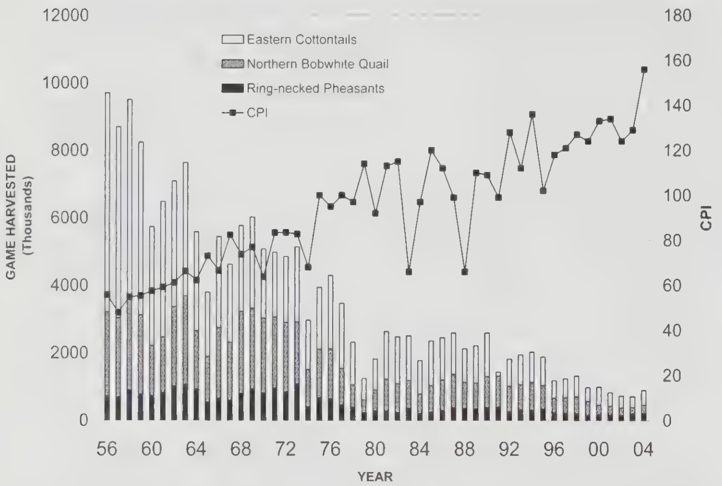

Figure 8.2. Upland Game and Crop Production Index (CPI) Illinois from the mid 1950s to present. (Data from the Illinois Department of Natural Resources and the Illinois Department of Agriculture). The CPI is a measure of total agricultural outputs in the state.

although these hunters were sometimes seen as river rats rather than providers. Illinois is a major migratory area, strategically located in the Mississippi Flyway (Fig. 8.5) between the breeding grounds to the north and the wintering grounds to the south. Aside from its prairies, one of the most prominent features of Illinois is the 273-mile Illinois River, the state's namesake (Fig. 8.8). Prior to the Wisconsinan glaciation, 400,000 acres in the present Illinois River floodplain had been carved by the Mississippi River, which entered the valley near Hennepin. Legions of Mallards (*Anas platyrynchos*) (Fig. 8.4) funneled down the ancient Mississippi River valley. For the last 10,000 years or so, the Illinois River, which now occupies this floodplain, has continued to host this traditional fall passage of waterfowl seeking the abundant food in its lakes, marshes, and forests. At the turn of the twentieth century, the Illinois River was one of the most productive rivers in North America and attracted millions of ducks. Consequently, the Illinois Valley produced some of the world's finest decoy carvers and call makers. Private clubs grew in number as the fame of Mallard hunting in the valley spread through the country.

With the passage of the Migratory Bird Conservation Stamp Act of 1934, legislation was implemented for the federal duck stamp program. The 1930s also witnessed the expansion of the National Wildlife Refuge

Figure 8.3. The Illinois River valley has provided essential habitat to migratory waterfowl for centuries. Shown here are Snicarte and Ingram lakes near Snicarte, Illinois. (Photo by M. Horath)

System and the initiation of international duck censuses and banding programs. The Federal Aid in Wildlife Restoration Act (Pittman-Robertson) enacted in 1937 provided financial aid to states for significant wildlife restoration projects. Shortly thereafter, biological studies of waterfowl in Illinois began with the employment of Arthur S. Hawkins and Frank C. Bellrose by the Illinois Natural History Survey (INHS) (Fig. 8.6) at a newly constructed field station located on the Chautauqua National Wildlife Refuge near Havana. This building was the first permanent structure at what was later to be named the Stephen A. Forbes Biological Station (Fig. 8.7). The station, established by INHS in 1894, is the oldest inland aquatic biological station in the nation (3).

Wetlands once occupied a fourth of Illinois landscapes (see Chapter 5) and provided habitat for nesting and migrating waterfowl as well as a multitude of other wildlife. Today, over 90% of Illinois wetlands are gone. Our rivers and their associated wetlands are subjected to the insidious and continuous effects of sedimentation and unnaturally fluctuating water levels (4). Yet, in spite of these losses and changes, wetlands, especially those associated with river floodplains, continue to provide essential habitat

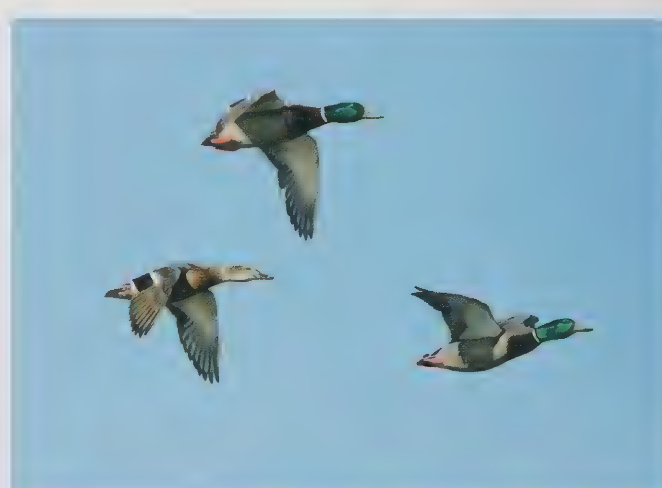

Figure 8.4. The Mallard is the most common species of duck in Illinois and North America. (Photo by J. Stafford)

Figure 8.5. Specific locations within and the general areas of the central Mississippi River valley, lower Mississippi River valley, Illinois River valley, and the selected cooling lakes and reservoirs in central and southern Illinois aerially inventoried for waterfowl by the Illinois Natural History Survey, 1948–2001.

Figure 8.6. Frank C. Bellrose (right) began his more than 60 years with the Illinois Natural History Survey in 1938. (Survey files)

Figure 8.7. The Survey's Stephen A. Forbes Biological Station has been located on Chautauqua National Wildlife Refuge since 1939. (Photo by M. Horath)

for waterfowl in fall and spring as their instincts honed by eons of time lead them along traditional migration corridors. Here in these various floodplains the aquatic and moist-soil plants provide seeds and tubers as well as invertebrates—the nutrients waterfowl require for the rigors of migration and other activities.

MALLARDS

In Illinois, the Mallard is the most abundant duck and the most highly prized by duck hunters. The Illinois River valley historically has been one of the most important migration areas for Mallards in the United States. The presettlement bottomland lakes of the Illinois Valley were well vegetated and the bottomland forests supported massive pin oaks and pecan hickories (5). The abundance of food attracted Mallards for hundreds of years. Frederick Lincoln, the first person to band ducks in the United States, placed bands on Mallards in 1922 in the Illinois River valley. Aldo Leopold (6) noted that law enforcement officers during 1928–1929 estimated that peak numbers of ducks reached 3 million on Crane Lake, 3 million on Clear Lake, and 500,000 on Meredosia Bay. The year when the most ducks visited the Illinois Valley, since 1938 when systematic estimates began (Fig. 8.8), was probably 1944, when over 3.8 million Mallards and American Black Ducks (*A. rubripes*) were documented during a single week (7).

The peak numbers of Mallards during fall in the Illinois River and the central Mississippi River regions for 1948–2006 indicate that the Illinois River region usually accommodates more Mallards than the central Mississippi River region (Fig. 8.3). For example, in 1948 a peak number of about 1.6 million Mallards was recorded for the Illinois River region compared with 181,400 in the central Mississippi River region. In recent years, however, differences in peak numbers between these two regions have become smaller. Unfortunately, the peak numbers of Mallards in the Illinois Valley have decreased markedly over the decades and typically hover around the 300,000 level in today's environment. However, the Illinois River and central Mississippi River regions are still critically important to Mallards. Conservatively, an average of about 32% of all Mallards wintering in the Mississippi Flyway passed through the Illinois and central Mississippi River regions from the mid-1950s until the mid-1990s (7).

LESSER SCAUPS

Lesser Scaups (*Aythya affinis*) (Fig. 8.10), a species of diving duck, were abundant in the Illinois Valley before the mid-1950s. After the initiation of aerial inventories in 1948, the largest concentrations of Lesser Scaups observed in the Illinois Valley occurred on Upper Peoria Lake when 700,000

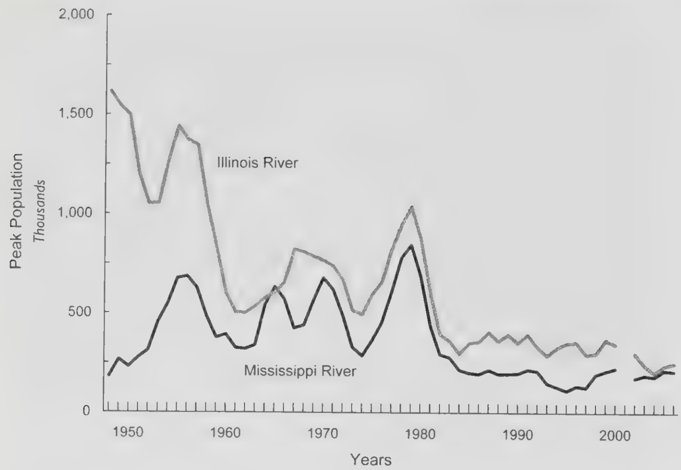

Figure 8.8. Three-year moving average of the peak numbers of Mallards aerially inventoried during fall in the Illinois River and the central Mississippi River regions, 1948–2000, 2002–2006. A three-year moving average is the average of the peak number for a specific year and the two previous years and is used to minimize annual fluctuations and to emphasize long-term trends.

were recorded in 1949, 550,000 in 1953, and 510,000 in 1948 (Fig. 8.9).

The decline in the numbers of Lesser Scaups using the Illinois River region and the increase in numbers stopping on Pool 19 in the central Mississippi River region since 1948 are apparent. A dramatic crash in peak numbers of Lesser Scaups, primarily on Upper Peoria Lake, occurred in the 1950s. The peak numbers of Lesser Scaups recorded in the Illinois River region north of Peoria declined from 585,100 in 1954 to 10,075 in 1957. Subsequently, the numbers of Lesser Scaups stopping in this area have never recovered. On Pool 19 in the central Mississippi River region, however, numbers of Lesser Scaups began to steadily increase after 1950 and reached a zenith of 685,500 in 1969. Unfortunately, the trend in numbers of Lesser Scaups has been downward since then.

CANVASBACKS

The highest number of Canvasbacks (*A. valisineria*) (Fig. 8.11), also a diving duck, inventoried in the Illinois River region occurred on Upper Peoria Lake and the Illinois River north of Peoria during the early 1950s. During that period, numbers ranged from 85,000 to 105,160 (Fig. 8.12). In

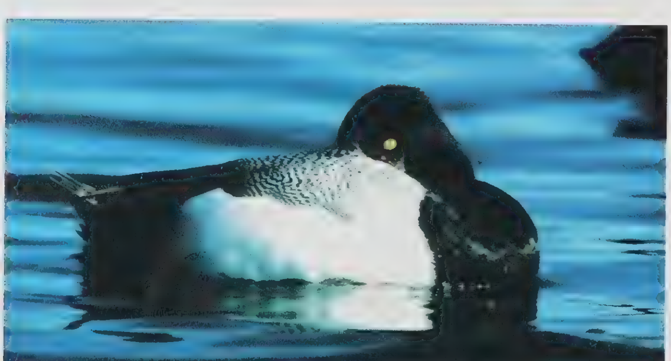

Figure 8.10. Lesser Scaups (male above) were once very common in the Illinois Valley. (Photo by T. Humburg)

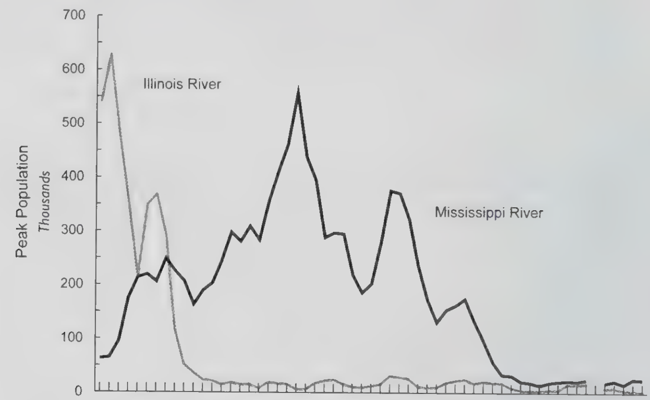

Figure 8.9. Three-year moving average of peak numbers of Lesser Scaups aerially inventoried during fall in the Illinois River and the central Mississippi River regions, 1948–2000, 2002–2006.

1971, a maximum of 120 were observed there. Similar to the numbers of Lesser Scaups, the numbers of Canvasbacks crashed in the Illinois River region in the 1950s and have not recovered to any reasonable levels. In the central Mississippi River region, the numbers of Canvasbacks began to increase in 1963, mainly on Pool 19, and after a downturn in the mid-

Figure 8.11. Canvasbacks (male) are considered a regal species of waterfowl. (Photo by T. Humburg)

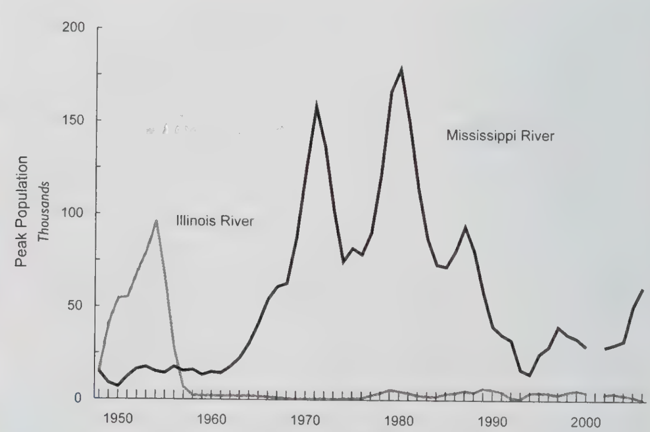

Figure 8.12. Three-year moving average of peak numbers of Canvasbacks aerially inventoried during fall in the Illinois River and the central Mississippi River regions, 1948–2000, 2002–2006.

1970s, reached their maximum number of 188,150 in 1978. Since 1978, their numbers have been sliding downward in this stretch of the Mississippi River.

WOOD DUCKS

One of the species of waterfowl that made a remarkable recovery in Illinois and the eastern United States during the twentieth century was the Wood Duck (*Aix sponsa*) (Fig. 8.13). By World War I, their population was so low that a national concern for their welfare arose (8). The Migratory Bird Treaty Act of 1918 resulted in a nationwide closed season that lasted until 1941 when some states permitted hunters to take one Wood Duck per day during the hunting season. Since then, largely through harvest regulations with the assistance of some management practices, such as the employment of artificial nesting structures, Wood Duck populations have recovered to the degree that they typically have ranked second in the duck harvest in Illinois and the Mississippi Flyway (7).

Figure 8.13. The Wood Duck (male) was nearly extinct in the early 1900's. (Photo by T. Humburg)

CANADA GEESE

The comeback of the Canada Goose (*Branta canadensis*), particularly the Mississippi Valley Population (MVP) and the giant race (see following section), signifies one of the major success stories in wildlife management. Canada Goose populations, along with those of the Wood Duck, have rebounded from critically low to abundant levels. Early European settlers wrote more about the Canada Goose than any other waterfowl species except swans (9). Today Canada Geese are probably more numerous than at any other period in history and currently breed in every province and territory of Canada and in 49 of the 50 United States (10). Canada Geese in Illinois consist mainly of the MVP and the semi-migratory Giant Canada Geese, two of the five management populations consisting of three races or subspecies of Canada Geese that occur in the Mississippi Flyway.

The Mississippi Valley Population of Canada Geese, originally defined on the basis of its wintering range (11, 12), consists primarily of the Interior race (Fig. 8.14). The principal nesting range of MVP geese is in northern Ontario, especially in the Hudson Bay Lowlands, west of Hudson and James bays. MVP Canada Geese primarily concentrate during fall and winter in Wisconsin, Illinois, and Michigan.

The earliest information on the MVP or Canada Geese in Illinois emanates from records of nineteenth century trappers and market hunters, and these accounts indicate that southern Illinois goose populations at that time numbered in the "many thousands" (13). Although no exact figures are available, declines in flocks using the sandbars of the Mississippi River were noticed as early as 1925 (13). The high harvest of Canada Geese, a species that traditionally wintered in southern Illinois, led to the establishment of Horseshoe Lake Wildlife Management Area in 1927, the first refuge in the state. By the early 1940s, numbers of wintering Canada Geese were declining in the Mississippi Flyway (12). Loss of habitat along the Mississippi River and excessive harvests throughout the flyway were taking a heavy toll. In January 1946, 53,530 Canada Geese were estimated in the flyway of which only 22,000 MVP geese were found at Horseshoe Lake Refuge in southern Illinois (14). Subsequent years of greatly restricted season lengths and bag limits and the creation of harvest zones and

Figure 8.14. The Interior subspecies of the Canada Goose has been a winter visitor to Illinois for centuries. (Photo by M. Horath).

additional refuge areas in the region successfully reduced the harvest. Numbers of geese soon began to increase. The MVP of Canada Geese improved from an apparent all-time low of 22,000 birds in 1946 to a fall flight estimate of about 1.45 million during 1990–1992 (15, 16). This population, the third largest management population of Canada Geese in the United States, falls just behind the giants composing the Mississippi Flyway Resident Population and the Atlantic Flyway Resident Population.

Today, Interior Canada Geese continue to exhibit a wider distribution than the historical range of the race in the state. In the 1970s, approximately 60% of the Canada Geese harvested in Illinois was taken in southern Illinois. By the early 1990s, only about 30% of the statewide Canada Goose harvest occurred there. In recent years, major migrations into southern regions of Illinois have been delayed and were significantly smaller than average. For the 2006–2007 migration, a population peak of 36,350 was recorded on January 29, 2007 (17). This is the lowest peak count recorded since surveys began in 1956–57. As the Giant Canada Goose population increased in size and distribution, the Interior Canada Geese altered their migration patterns (18).

GIANT OR RESIDENT CANADA GEESE

The historic nesting range of the Giant Canada Goose, the largest race in North America, covered more area and included a larger diversity of habitats and climates than that of any other goose (9). The unregulated hunting, egg gathering, and wetland destruction that accompanied the nineteenth century settlement of its breeding range decimated the Giant population. At least nine people had written about its extinction (19). Hanson (9), however, discovered a wintering, free-flying population of Giant Canada Geese at Rochester, Minnesota, in January 1962. Subsequent successful restoration programs throughout the flyway, combined with the Giant's high reproductive and adult survival rates, have fostered the growing populations that exist today. Their numbers are also enhanced by their tolerance to human disturbance, the willingness to nest in close proximity to others, and their relatively short migratory flight to wintering areas compared with the migratory distances of other races.

Figure 8.15. The Giant or Resident subspecies of the Canada Goose, once thought to be extinct, is now common throughout North America. (Photo by M. Horath)

The Giant Canada Goose is now a nuisance animal in several metropolitan areas. It occupies all of its former range as well as all states and provinces in the Mississippi Flyway (20) (Fig. 8.15). Instead of being extinct or endangered today, the Giant Canada Goose is the most important goose in the harvest of many states and provinces and has had major implications for management of all Canada Geese in the flyway, including hunting regulations and the ability to limit the harvest of other races of Canada Geese.

The Mississippi Flyway population of Giant Canada Geese increased about 6% annually during the late 1990s. (21). The hesitancy of Giant Canada Geese nesting at northern latitudes to migrate southward until the onset of severe winter weather likely contributes to the delay in the migration of Interior Canada Geese noticed in recent years. Giant Canadas are also adept at using nontraditional migration and wintering locations, such as metropolitan and urban areas that offer ice-free roosting sites on ponds, rivers, lakes, food resources in nearby agricultural fields, and no hunting disturbance. As a result, the movements and concentrations of Giants influence the migration and distribution of Interior and other races in the flyway.

Restoration of Giant Canada Geese in Illinois was initiated by the Department of Conservation in 1967. As a result of relocation, protection, and habitat management programs, Giant Canada Geese now nest in every county. They nest on reclaimed strip-mined lands, large reservoirs, lakes, streams, natural marshes, and farm ponds throughout Illinois. Moreover, they readily nest in metropolitan and suburban areas. Giant Canada Geese have even been documented nesting on the roof tops of office buildings in Wisconsin (22).

SNOW AND WHITE-FRONTED GEESE

In the last decade or so, Illinois has hosted increased numbers of Lesser Snow Geese (*Chen caerulescens*) and White-fronted Geese (*Anser albifrons*), particularly in spring. The Lesser Snow Geese visiting Illinois include both the white and blue color phases (Fig. 8.16). These mid-continent snow geese nest on Baffin and Southampton islands, with smaller numbers nesting along the west coast of Hudson Bay. They winter primarily in eastern Texas, Louisiana, and Arkansas. Their numbers have increased since the 1970s with an abundance of 777,000 in 1969/1970 to about 2,222,000 in 2005/2006 (23). Generally, an average of 15,000 to more than 40,000 were inventoried during fall in Illinois during the last half of the 1900s (7) with the majority present in the Illinois and Mississippi River floodplains. Now, for unknown reasons, they appear in substantial numbers during spring in Illinois. Since 1995, as many as 565,200 (February 1, 2005) were inventoried in southern Illinois and 86,000 (February 11, 2002) were documented in central Illinois (24).

The mid-continent population of White-fronted Geese (Fig. 8.17) nest across a broad region from central and northwestern Alaska to the central Arctic and the Foxe Basin. They concentrate in southern Saskatchewan during the fall and in Texas, Louisiana, Arkansas, and Mexico during winter. Numbers of White-fronted Geese have increased in recent years in Illinois. In January 2007, more than 16,400 were inventoried (17). This interesting species of goose, with its high-pitched, laughing call and handsome appearance, is one of more than 20 species of migratory waterfowl that pass through Illinois each fall and spring.

MANAGEMENT OF WATERFOWL

As with any game species, management of their populations is done largely through hunting regulations and policies and habitat programs. To the benefit of waterfowl, flyway councils (Atlantic, Mississippi, Central, and Pacific) were established in 1952 to improve waterfowl management. Along with the Migratory Bird Treaties of 1913 and 1918, their formation was perhaps the most important step that had thus far been taken in waterfowl management. The Mississippi Flyway Council was organized on January 24, 1952, and its Technical Section of waterfowl biologists was organized the following July. With the establishment of the flyway councils, state and federal cooperative waterfowl management programs emerged. Hunting seasons and bag limits have been set individually for each flyway,

Figure 8.16. Lesser Snow Geese are frequent visitors to Illinois, especially in spring. (Photo by Michelle M. Horath)

Figure 8.17. White-fronted Geese are now more commonly seen in Illinois. (Photo by M. Horath)

but each state has had some leeway for setting its own regulations within the federal flyway framework. The USFWS adjusts daily bag limits almost yearly in response to harvest objectives. Restrictive bag limits are set when duck populations are low; more liberal bag limits are established in years of high duck production and favorable habitat conditions. In 1995, the USFWS implemented new procedures for determining duck harvest regulations, the Adaptive Harvest Management Strategy, which standardizes duck harvest regulations into restrictive, moderate, and liberal alternatives based upon population levels and breeding ground conditions.

Although habitat on public lands and the state and federal duck stamp programs are extremely important, the future of waterfowl in North America will be dependent upon habitat programs on private lands. Most wetlands (74%) in the United States occur on private property (25). Agricultural programs and policies, such as the Farm Bills with the Conservation Reserve Program, the Wetland Reserve Program, and conservation compliance, will affect millions of acres of waterfowl nesting and breeding habitat. Those private organizations concerned with waterfowl protection issues include Ducks Unlimited, the National Audubon Society, Delta Waterfowl Foundation, and The Nature Conservancy. Of course, private waterfowl clubs, abundant in Illinois, provide important wetland habitat, resources, and refuges for waterfowl and other species. Since the mid-1980s, wetland losses appear to be slowing, largely as a result of conservation programs on private lands.

LEAD POISONING IN WATERFOWL

No discussion of waterfowl and waterfowl management would be appropriate without paying tribute to Frank C. Bellrose and his associates at the Illinois Natural History Survey (INHS). Bellrose, a world renowned waterfowl biologist, began his carrier at the INHS in 1938. He devoted much of his research in the 1940s and 1950s to lead poisoning, a toxicosis provoked when birds ingest spent lead shotgun pellets (Fig. 8.18). These efforts culminated in a landmark publication in 1959, appropriately titled *Lead Poisoning as a Mortality Factor in Waterfowl Populations* (26). Bellrose's work was reinforced and expanded by additional publications produced by other INHS scientists (27, 28, 29, 30, 31, 32). Together, these papers formed much of the database for determining that lead poisoning was an unacceptable problem in waterfowl populations and that lead shot should be replaced with nontoxic shot for waterfowl hunting.

HISTORY AND PREVALENCE OF LEAD POISONING

The first documented cases of lead poisoning in waterfowl date back to 1874 when, according to Phillips and Lincoln (33), the disease was noted in ducks at a lake near Galveston, Texas (Fig. 8.19). Lead poisoning was subsequently recorded in waterfowl in many states and other countries (26:238-239, 34:7). In Illinois from 1940 to 1986, 16 lead poisoning die-offs, involving the loss of approximately 25,000 waterfowl, were documented (Fig. 8.20) (26, 28, 35). Most die-offs occurred during the late fall and early winter months after close of the hunting season (Fig. 8.21) (7:455).

As unfortunate as these die-offs are, they represent only the "tip of the iceberg." Most lead-poisoning mortalities—i.e., the day-to-day drain on the population—go unnoticed (36:16–17). William F. Nichols elegantly penned the following observation of sick and dying ducks disappearing from the edge of ice at Horseshoe Lake in Madison County: "The mystery was solved when I saw a dying bird attacked by three gulls and the carcass entirely stripped clean of all flesh in a 24-hour period. A pile of feathers and the bones were all that remained, and in most cases the remains were dragged into the water and sank from sight and all evidence of the death was removed in a natural process" (letter in *Illinois Wildlife* 22 April 1981).

The incidence of ingested shotgun pellets in the gizzards of Mallards (Fig. 8.22) harvested by hunters in Illinois averaged 6.4% to 7.9% from 1938 to 1997 (26:262, 29:183, 30:849) (Fig. 8.23). For Mallards in the entire Mississippi Flyway, the incidence was 7.8% to 8.9% during these same years. In assessing these data, one needs to be mindful that we are viewing a static picture or "snapshot"

Figure 8.18. Frank C. Bellrose examining lead-poisoned Mallards in the 1950s. (INHS files)

Figure 8.19. A lead-poisoned Mallard showing typical disease symptoms, such as the wings assuming a "roof-shaped" position over the back. (INHS files)

Figure 8.20. A lead-poisoning Mallard die-off in the Illinois River valley during the late 1940s. (INHS files)

of a dynamic process. To quote Bellrose (26:280), "Daily during the fall and winter months, some ducks in the North American population are ingesting shot pellets, some are voiding them, some are dying from their effects, and some are recovering." Bellrose (26:281) estimated that approximately one-fourth of the wild Mallards of North America in any one year ingest shotgun pellets.

In his studies, Bellrose (26:282) estimated that 4% of the Mallards in the Mississippi Flyway, and 2–3% of all waterfowl species in North America, died annually from lead toxicosis. Although Bellrose's methodologies have been scrutinized for nearly 50 years, they have never been discredited and are recognized today as pioneering research that has withstood the test of time (30:855).

In addition to waterfowl, lead poisoning due to ingestion of lead shotgun pellets has been documented in 52 other species of free-ranging birds (37). Cases of lead poisoning in Ring-necked Pheasants (*Phasianus colchicus*) were among the first reported for birds (38). The toxicosis has been repeatedly documented in the Bald Eagle (*Haliaeetus leucocephalus*), a species that winters and nests in Illinois (39). Eagles contract the toxicosis secondarily by feeding on flesh and internal organs of hunter-crippled and lead-poisoned waterfowl (40). Recent research in Missouri suggests that lead poisoning may be a major mortality factor in Mourning Dove (*Zenaida macroura*) populations (41, 42).

Figure 8.21. Lead-poisoned ducks float in Quiver Creek, Mason County, Illinois, in front of a hunting blind after the close of a waterfowl season in the 1980s. (Photo by S. Havera)

In concluding his landmark paper, Bellrose (26:286) stated, "At the present time, lead poisoning losses do not appear to be of sufficient magnitude to warrant such drastic regulations as, for example, prohibition of the use of lead shot in waterfowl hunting. Sixteen years later, Bellrose

Figure 8.22. Ingested lead pellets present in a Mallard gizzard. (INHS files)

(43:167) altered his assessment of lead poisoning and proposed replacing lead shot with nontoxic (steel) shot. The next year, 1976, the U.S. Fish and Wildlife Service released its Final Environmental Statement for Proposed Use of Steel Shot for Hunting Waterfowl in the United States.

THE ERA OF NONTOXIC SHOT

Attempts to resolve the problem of lead poisoning in waterfowl populations date back to the 1930s, when Green and Dowdell (44) and Dowdell and Green (45) published papers on the use of lead-magnesium alloys as a nontoxic substitute for lead shot. In theory, shot made with the alloys would disintegrate when exposed to water or the acid environment in a gizzard, thereby rendering the shot harmless to waterfowl. However, efforts to produce lead-magnesium shot commercially were unsuccessful, and follow-up testing revealed the shot was toxic.

In 1964, in a report entitled "Wasted Waterfowl," the Mississippi Flyway Council Planning Committee recommended finding a nontoxic replacement for lead shot for waterfowl hunting. In 1965, staff of the U.S. Bureau of Sport Fish and Wildlife (now the U.S. Fish and Wildlife Service) met with members of the Sporting Arms and Ammunition Manufacturer's Institute (SAAMI) to discuss lead poisoning and the development of a nontoxic shot. Research conducted in the late 1960s at the Illinois Institute of Technology and elsewhere determined that the only viable substitute for lead shot for waterfowl hunting was soft iron (steel) shot (46).

Nontoxic shot was first promulgated for waterfowl hunting beginning in 1972, when it was required on selected national wildlife refuges (47:57). The conversion to nontoxic shot progressed little through 1976, increased to about 10% in 1977 through 1985, accelerated rapidly in 1985, and became nationwide in 1991 (Fig. 8.24). In Canada, nontoxic shot regulations became nationwide beginning with the 1999 season (48).

Through the 1993 season, steel shot was the only type of shot approved as nontoxic by the U.S. Fish and Wildlife Service. Bismuth-tin shot was added in 1994, following toxicity testing conducted at the INHS (49). Tungsten-iron shot was approved in 1997. Since that time, a host of tungsten-based shots have been approved as nontoxic (50). Zinc shot was also considered, but testing at the INHS found it toxic to waterfowl (51). The development and marketing of these many new shot types serve as an excellent example of industry successfully changing to meet the needs of both hunters and conservation. Some of the new nontoxic shots are actually heavier (denser) than lead, which has historically been viewed as the "gold" standard for loading shotgun shells.

The 15 shooting trials that were conducted on waterfowl in the United States pitted steel shot against lead shot and produced variable results. For some, lead shot out performed steel, for others steel produced fewer cripples, and in the majority the results were mixed (52:96). However, in critiquing the advantages and disadvantages of lead and steel shot, one must compare losses due to crippling from steel with losses due to crippling from lead, plus waterfowl deaths from lead poisoning, plus indirect losses due to "sublethal" effects of lead (Fig. 8.25), plus poisoning of non-waterfowl species (52:96). The latter includes threatened and endangered species.

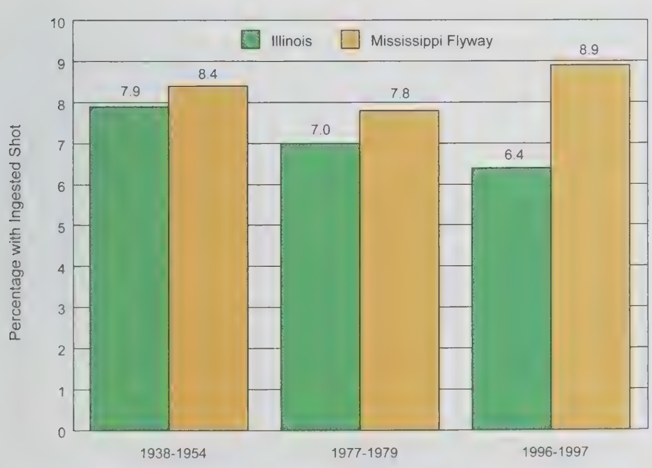

Figure 8.23. Prevalence of ingested shotgun pellets in gizzards of Mallards harvested in Illinois and in the Mississippi Flyway from 1938 to 1997 (26, 29, 30).

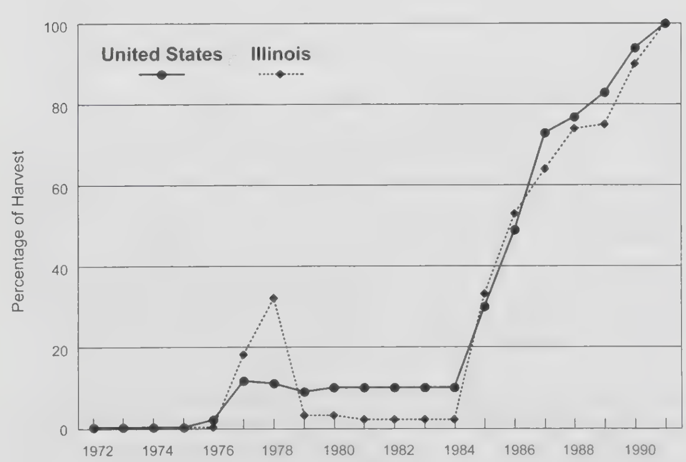

Figure 8.24. Percentage of waterfowl harvest in nontoxic shot zones in Illinois and in the United States from 1972 to 1991 (7).

The history of the implementation of nontoxic shot regulations for waterfowl hunting in Illinois and throughout the United States is punctuated with delays, small steps forward, setbacks, and eventual success (47:56). Fueling this controversy was mounting evidence that lead poisoning was a problem for waterfowl and the Bald Eagle and, on the opposing side, organized resistance among hunters who believed steel shot was ballistically inferior to lead shot. Those opposed to steel shot first used the judicial process (law suits) in 1976, and they began using the legislative process two years later. Over the next decade, additional lawsuits and legislation were brought into play by both sides and at both the state and federal levels.

Counting appeals, there were 10 legal challenges to nontoxic shot regulations for waterfowl hunting. All were unsuccessful. The courts consistently accepted the scientific evidence that lead poisoning was a problem for waterfowl and rejected arguments that steel shot was unsuitable for waterfowl hunting (53). In 1985, a law suit won by the National Wildlife Federation tipped the balance in favor of nontoxic shot regulations.

The initiation of nontoxic shot regulations immediately reduced exposure of waterfowl to toxic lead shot. To illustrate, 16% of ingested shot in Mississippi Flyway Mallards was steel in 1977, the first year for nontoxic shot use in that flyway (29:183). The percentage increased to 19% in 1978, then to 26% in 1979. In a more recent study, conducted five to six years after nationwide implementation of nontoxic shot regulations (30:855) researchers reported that lead poisoning losses of Mallards in the Mississippi Flyway were reduced by 64%. These researchers estimated that, nationwide, 1.4 million ducks were spared death from the disease in 1997. In addition, catastrophic lead poisoning die-offs have all but disappeared from the landscape.

The implementation of nontoxic shot for waterfowl hunting has proven to be a highly successful undertaking that has benefited the waterfowl resource, hunters, firearms manufactures, the ammunitions industry, and wildlife managers, alike. The nontoxic shot program, highlighted by the numerous waterfowl and other avian species it saves, stands as a monument to Frank C. Bellrose and his INHS associates for their pioneering research on the problem of lead poisoning in waterfowl populations (Fig. 8.26).

THE ERA OF ABUNDANT SMALL GAME ON FARMLAND

The peak abundance of many small mammalian game species occurred during agricultural expansion in the late 1800s when high-energy food grains became part of the landscape and farming proliferated early succession cover. These spikes in game numbers occurred with a high diversity and density of avian and mammalian predators, such as the Red Fox (*Vulpes vulpes*).

The general compatibility of farming and upland wildlife, as well as the need for more careful game management, was evident to practitioners of wildlife management. The following was described in the 1930 Report to the American Game Conference on an American game policy by the Committee on Game Policy, Aldo Leopold, Chair (54):

> *The management measures most needed for farm game are slight modifications of farm practices to provide cover and food, control of those predators known to be injurious, and regulation of the kill.*
>
> *We are convinced that only bold action, guided by as much wisdom as we can muster from time to time, can restore America's game resources.*

The trends in Eastern Cottontails (*Sylvilagus floridanus*), Ring-necked Pheasants, and Northern Bobwhites (*Colinus virginianus*) taken by hunters show that since World War II there has been a gradual parting of ways between agriculture and farmland game (Fig. 8.5). These species thrived in landscapes comprised of small, diversified livestock and grain farms with rotations of feed grains, forage grasses, and legumes (55). Subtle variations in the nature and timing of farming disturbances largely described fluctuations in the abundance of such species over time and space. Periodically, farm set-aside programs caused upturns

Figure 8.25. Blood sample for determining lead concentration being drawn from the wing of a Mallard. (Photo by M. Horath)

Figure 8.26. Duck pens in the 1950s where lead poisoning studies on waterfowl were conducted at the survey's Forbes Biological Station near Havana, Illinois. (INHS files)

in small game numbers, as early succession vegetation was established with minimal farm disturbances during the reproductive season (56). In general, the downward trends in farmland game species in Illinois have been more pronounced than elsewhere in North America because of the intensity of the cropping systems. Thus, the pendulum has swung. Early agriculture in Illinois was a showcase for how farming and abundant small game can coexist. Modern agriculture as it has emerged in this state has been a harbinger for a tenuous coexistence of small game and farming that is now more widely appearing on this continent and in other intensively cropped parts of the world.

By the 1960s, clean farming characterized by intensive corn and soybean cropping systems began to rapidly emerge. Field and farm sizes grew and the vegetation types and spatial arrangements on the landscape were greatly simplified. Grassy and other early succession cover, including field edges and other nonagricultural cover, disappeared. During the mid- to late 1900s the reach of agriculture was profound in homogenizing habitat features, both distinct and subtle. The habitat needs for upland game are now no longer accommodated within the intensive row crop farming that dominates rural Illinois (Fig. 8.2).

Game species recently on the rise, such as White-tailed Deer, can exploit a wide range of landscape and habitat conditions. As noted by Roseberry (57), little habitat has been developed specifically for these species. They are mobile, opportunistic, and flexible in their behavior and have thrived within the framework of sport hunting regulations.

FORESTS AND FOREST GAME

In 1820, an estimated 42% of Illinois or nearly 15 million acres was forested (see Chapters 3 and 4). These magnificent forests sheltered untold numbers of wildlife species many of which began declining in abundance almost immediately with the advent of European settlement. It is true, however, that before the advent of cheap rail and water transportation, the native forests were a vital necessity to the pioneers. Between 1830 and 1855, forest land was valued above prairie. Forest fires were controlled, forest plantations were started, and livestock was fenced out of forest land (58). After lumber became available from out of state, forest lands were cleared for crops or pasture, repeatedly burned or high graded for lumber, and reduced to less than 3 million acres by 1920 (59). Today, forests cover about 4.5 million acres of the Illinois landscape (see Chapter 4).

Forest game species have had to adapt to the fragmented nature of today's landscape. Those species with a more generalist life style such as White-tailed Deer, have thrived while those confined to forest habitat, such as squirrels and Wild Turkeys (*Meleagris gallopavo*), are a product of the extent and productivity of the remaining forests. The following species are discussed because they are common throughout the forests of the Midwest and Illinois, are important game species, and are readily observed by the public.

GRAY AND FOX SQUIRRELS

Both Gray Squirrels (*Sciurus carolinensis*) and Fox Squirrels (*S. niger*) were abundant in Illinois at the time of European settlement. The early settlers described the immense numbers of squirrels that were often a menace to food crops in the early years. Gray Squirrels (Fig. 8.27) were confined to the larger hardwood forests, but Fox Squirrels (Fig. 8.28) were most abundant on the prairie-forest edge (60). As the settlers began to clear the forests, Gray Squirrels began declining

Figure 8.27. Gray Squirrels prefer extensive tracts of forest in Illinois. (Photo by S. Havera)

in abundance and distribution because they prefer extensive forests. Fox Squirrels were able to adapt to the woodlots and hedgerows created by the farms and cities growing throughout Illinois. Niche occupancy by each species appears to function through habitat specialization rather than through food finding methods or dietary differences (61). By the late nineteenth century both squirrel species were becoming scarce. In 1889, the Illinois legislature imposed the first hunting season and as numbers continued to decline, enacted a daily bag limit beginning in 1919. Season lengths have since varied, with various zones and opening dates throughout the state (62).

Fox Squirrels are present today in all 102 Illinois counties, but Gray Squirrel distribution is more fragmented (62). Based on recent figures, harvests of Gray Squirrels varied from 356,000 in 1999 to 772,000 in 2004 while Fox Squirrel harvests varied from 396,000 in 2005 to 786,000 in 1998 (63). Based on hunter surveys from 1999 through 2003, Gray Squirrels were not reported from Livingston, DuPage, Kane, Kankakee, Dewitt, and Ford counties (64). This is not to say that Gray Squirrels are not present in these counties but only that hunters did not report them. In some of these counties, Grays are present in forest reserves or urban areas that are closed to squirrel hunting.

Gray and Fox squirrels are likely to remain abundant in Illinois for the foreseeable future as our forests continue to recover from past abuse. Fewer forests are being pastured and more intelligent forest management practices are used today compared to past years. Forests are also maturing and producing more winter storable seed (such as acorns and hickory nuts) for squirrels and other wildlife. However, a large deer herd that is reducing oak-hickory reproduction and a shift in tree species toward those more mesic-loving trees (see Chapter 4), such as Sugar Maples (*Acer saccharum*), will likely reduce squirrel food production in future years.

Figure 8.28. Fox Squirrels are able to exist in hedgerows and isolated woodlots as well as extensive forests. (Photo by S. Havera)

WHITE-TAILED DEER

Prior to European settlement, White-tailed Deer (Fig. 8.29) densities were probably highest on islands, around marshes, and in the woodland-grassland junction that separated the eastern forests from the tallgrass prairies of the Midwest (65, 66). Illinois may well have been near the center of deer abundance on the continent before Europeans began a systematic reduction in numbers after settlement. However, deer numbers actually increased in Illinois for a short period between 1820 and 1850 because the larger deer predators and the Indian tribes that preyed on deer were removed or exterminated (67). Year-round market hunting and destruction of forests soon began reducing deer numbers, and in 1853, the Illinois legislature prohibited deer killing between January 1 and July 20 in northern Illinois and Sangamon County in central Illinois (68). Between 1850 and 1870, the human population of Illinois increased to more than 2.5 million, and deer numbers continued to decline. In 1873, the killing of deer was prohibited between January 1 and August 15, but this prohibition was a case of too little too late, and the hunting season was finally closed completely in 1901 after deer had been nearly exterminated (69). There were no wild deer seen in northern Illinois after 1874, in central Illinois after 1880, and in southern Illinois after 1910 (69).

Releases of deer from captive herds provided the nucleus for a rapid recovery in northern Illinois after 1903 (69). So quickly did deer respond to protection, that numbers reached nuisance proportions along the Rock River by the 1920s (6). The trapping and transplanting of deer from refuges located in the northern counties and one or two sites in southern Illinois restocked much of the state, and carefully regulated hunting was resumed in 1957, when 1,735 deer were harvested in 33 counties (68). Regulated harvests have been continued ever since, with harvests exceeding 100,000 deer in recent years. The harvest of deer has been increasing elsewhere in the Midwest as it has in Illinois.

High deer populations, while welcomed by hunters, have proved to be a serious problem affecting farm crops and the distribution and abundance of understory plant species in many forests and protected natural areas throughout the state (70, 71). In addition, deer aid in the distribution of ticks carrying Lyme Disease and Rocky Mountain Spotted Fever. Recently, deer populations in northern Illinois have also have been infected with Chronic Wasting Disease, a neuron-degenerative and potentially fatal disease of wild ruminants. Deer have also been implicated in the dispersal of aggressive non-native plants (70), such as Garlic Mustard.

Future deer management efforts will be directed toward control of deer numbers throughout Illinois and elsewhere in the Midwest. This effort will be difficult because: (1) the increasing urbanization of Illinois, creating thousands of refuges from hunting and more potential problems with deer depredations of landscape plants, and disease transmissions by tick carrying deer (72); (2) the high incidence of dispersal behavior of both sexes. This behavior among female White-tails is unique to the Midwest and Great Plains where limited forest cover makes it difficult for females to locate an exclusive parturition area (73). Female dispersal means that localized efforts to control deer will need to be very intensive and continuous in order to achieve population objectives; and (3) the creation of leasing agreements for deer hunting that often results in the underharvest of female deer as hunters search for a trophy buck on leased areas.

WILD TURKEYS

Prior to European settlement, the Wild Turkey (Fig. 8.30) was very abundant, found mostly in forest habitat but

Figure 8.29. White-tailed Deer have flourished in Illinois in recent decades. (Photos by M. Horath)

also in prairies some distance from the forest edge (74). Turkeys were a favorite food of the early settlers, and year-round hunting and forest destruction soon decimated their populations. Wild Turkeys were considered extinct in the state by 1903 (75).

In 1959, the Illinois Department of Conservation began releasing turkeys in southern Illinois that had been wild trapped in other states. By 1970, Illinois biologists began trapping turkeys from established flocks in Illinois and transplanting them throughout the state. By the 1990s, turkeys were present in virtually all suitable habitats in Illinois. Spring turkey hunters harvested over 16,000 turkeys in 99 counties in 2006 (IDNR, unpublished data).

Turkeys are currently managed according to county management units. Population indices are based on observations by deer hunters in the fall and turkey harvest statistics obtained from spring and fall hunts (75). Biologists have long known that turkey populations in northern environments can vary as much as 50% annually, due to changes in hen survival and reproductive success (75). Unfavorable weather in spring and summer, predation by Coyotes (*Canis latrans*) and other species, hunting, poaching out of season, disease, and parasites all affect turkey numbers from year to year (76).

Turkey populations should remain relatively stable in future years due to the conservative harvest approach used by the Illinois Department of Natural Resources. Turkeys have adapted fairly well to the fragmented nature of the current landscape and the constant presence of humans throughout the state. Their recovery from extirpation has been a welcome return to the fauna of Illinois and throughout North America.

Figure 8.30. The Wild Turkey has made a remarkable reappearance on the Illinois landscape. (Photos by M. Horath)

HUMAN PERCEPTIONS OF GAME ANIMALS

The children must be drawn towards and not away from the woods and fields and waters and must be led to see more clearly that . . . a man cut off from fellowship with the creatures of the open air is like a tree deprived of all its lateral roots and trimmed to a single branch. He may grow down and up, but he cannot grow out. His resources of enjoyment are so narrowed that he is often an object of pity when seen away from the city street. (Stephen A. Forbes 1891)

Citizens' perceptions and use of game animals have changed just as dramatically as game populations and their habitats. When most of the population had direct connections to the land, hunting was common and game animals were valued for food and sport. Especially in recent decades, the popularity of sport hunting on farmland game has waned with fewer people living on the land and diminished game and opportunities to hunt.

A recent benchmark study of the perceptions of wildlife resources by Illinois citizens leaves no doubt that attitudes about game are changing as dramatically as game populations (78). About 32% of Illinois citizens tend to believe that habitats support unlimited numbers of animals (i.e., are not resource limited). Urban citizens are prone to attribute imperiled species to overexploitation rather than to habitat destruction. These people also tend to value wildlife similar to pets or humans. They tend to identify with the challenges of habitat loss and biodiversity globally, but not locally. Further, there is an ebbing interest by urbanites in hunting, thus reducing hunting-related revenues that have been the mainstay of wildlife conservation in this country.

To Illinois citizens, wildlife management issues are increasingly perceived at the extremes. At one extreme, highly visible animals, many of them large game species, are threatened all over the world. At the other extreme, species of game animals, such as the Mallard, Giant Canada Goose, White-tailed Deer, Wild Turkey, and Coyote, that can adapt to man's influences and our changing environments have done well and should continue to do so where habitat allows. Those species which cannot adapt as easily, such as the Greater Prairie Chicken (*Tympanuchus cupido*), face uncertainty along with the habitats strongly influencing their populations. Wildlife habitats face enormous challenges and pressures with ever-increasing human populations, the enormous demands on natural resources, unquenched thirst for more development, the burgeoning numbers of on- and off-road vehicles, our unabated dependence upon pesticides at the landscape level, a growing demand for ethanol, and an escalating number of non-native species, both plants and animals. The quality, quantity, and distribution of habitats are critical factors affecting many wildlife populations. Agricultural policies are the primary agents affecting most of our habitats, and, therefore, the populations of wildlife. Sound ecological policies and regulations in concert with wise management practices are essential in providing desirable habitats in the future.

Although the ensuing decades will provide many challenges to wildlife populations, there is a wealth of relevant knowledge available from previous research endeavors and management practices. New technological methods will reveal heretofore unknown answers to essential questions in wildlife research. Perhaps more importantly, there is a need for a strong land ethic, as noted by Aldo Leopold, that incorporates into our policies and practices a deep appreciation of our natural resources, especially water, soil, and land, which are not only important to wildlife species but to our ecological well-being and economy as well.

The future management of game animals will be affected by the sweeping alterations of ecological systems and their inherent checks and balances. We have a limited ability to predict how species will adapt to humans and altered landscapes over time. While the particulars of game-habitat-human interactions will continue to be dynamic and unpredictable, it is clear that the public is increasingly focusing on a small subset of the extremes, sometimes arbitrarily deciding what species are important. Just as Shabonee bemoaned the fading of the Elk and a way of life, before our eyes the more adaptable small game species that were part and parcel of rural life in Illinois and the Midwest, such as Greater Prairie Chickens, Eastern Cottontails, Ring-necked Pheasants, and Northern Bobwhites, likewise seem headed toward the distant past.

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CHAPTER 9

Illinois Fish Communities: More than a Century of Change

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"*From time to time for more than a hundred years, ichthyologists at the Illinois Natural History Survey and other agencies have conducted censuses of Illinois fishes so that, in a sense, changes in the aquatic environment have been monitored all this time*"—(1)

OBJECTIVES

From time to time and over a 130-year period, collections of Illinois fishes have been made in all the major and minor waterways, lakes, and bordering rivers of the state. Analyses of these collections have revealed distinctive fish communities that have maintained relative stability and persistence over a century of time. For example, the indigenous Lake Michigan fish fauna is entirely different from that found on the Coastal Plain of extreme southern Illinois. Here we describe seven fish communities and discuss the future fish fauna of Illinois as predicted from the number of fish extinctions (10 so far) that have already occurred and the number (>20) of exotic invasive species that are now established members of the state's fish fauna. Some rare species that were once thought extinct are still members of the Illinois fauna pointing to the long-term resiliency of certain species and the need for continued monitoring of a state that has a more complete historical record of fish communities than any other in the world.

INTRODUCTION

Beginning in the mid-1960s, Illinois Natural History Survey ichthyologist and herpetologist Philip W. Smith (1922–1986) published a series of papers (1, 2), and ultimately a book (3) on Illinois fishes, emphasizing what has become one of the major paradigms of ecology, i.e., that communities can change dramatically—both in richness and abundance—in relatively short periods of time. In Illinois, Smith took advantage of a unique data set on fishes, a much earlier statewide survey of all major water systems commencing in 1876 and ending in about 1903 by Stephen A. Forbes and Robert E. Richardson (4). From 1962 to 1972, Smith assembled another and more comprehensive state-wide survey of fishes, providing him with the opportunity to document and compare changes in the state's fish fauna that had occurred since the survey of Forbes and Richardson (Figs. 9.1–9.3). A third comprehensive data set on Illinois fishes is now computerized and mostly on-line (Figs. 9.2 and 9.4). These more recent (post-1980) collections have been enhanced by basin surveys conducted under the authority of the Illinois Department of Natural Resources and the Illinois Environmental Protection Agency (e.g., 5,6). These "basin" surveys, began in the early 1990s and continued through the present, are sorted, catalogued and stored at the Illinois Natural History Survey (INHS) and Southern Illinois University Carbondale (SIUC). A comparison of these three major statewide surveys (Figs. 9.1–9.4) provides a unique opportunity to document the change in Illinois fish communities. No other state, province, or other political region in the world has such a detailed history of comprehensive fish-faunal surveys as does Illinois.

For comparative purposes Smith (1) divided Illinois into 33 stream systems, an approach still in use today (e.g., 7). For purposes here, we have divided Illinois into a few major and minor fish communities in an attempt to point out the uniqueness of these communities and some of the changes in richness and abundance that are readily apparent over the approximate 130-year time period. Our discussion focuses primarily on streams since, with the exception of glacial lakes in northeastern Illinois, most lakes in the state are man-made and their fish communities are far from natural.

IMPACT OF STREAM CHANGES ON FISHES

Factors responsible for the decline or disappearance of native fishes are variable and have previously been discussed by Smith (1) and Page (8). These factors affect other aquatic organisms as well and are probably the principal threats to stream biodiversity. The primary factors fall into seven categories: 1) soil erosion resulting in high sediment loads in streams; 2) the drainage of natural wetlands; 3) reduction in the water table and groundwater pollution; 4) interactions among native fishes and non-indigenous species; 5) stream

Figure 9.1. Sampling locations of fishes made from 1876 to 1903 in Illinois. After Forbes and Richardson (1909).

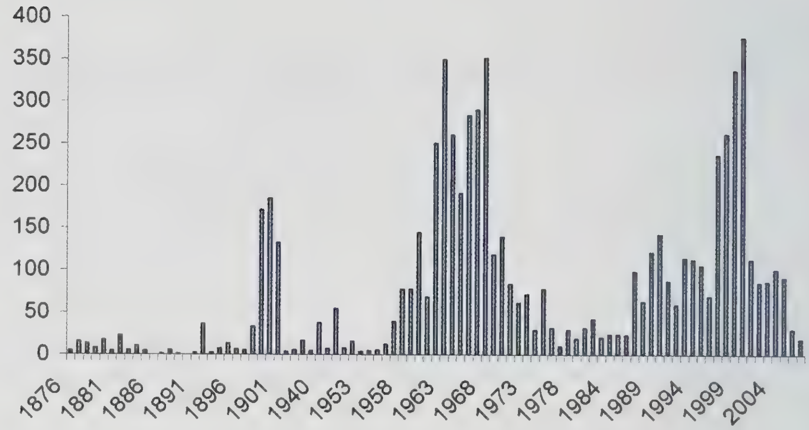

Figure 9.2. Temporal distribution of fish collections (sample taken at a single location at a single point in time) in Illinois during the Forbes/Richardson era (1876–1903), Smith era (1950–1978), and "modern" era (1980–2007).

Figure 9.3. Sampling locations of fishes made from 1950 to 1978 in and near Illinois. After Smith (1979).

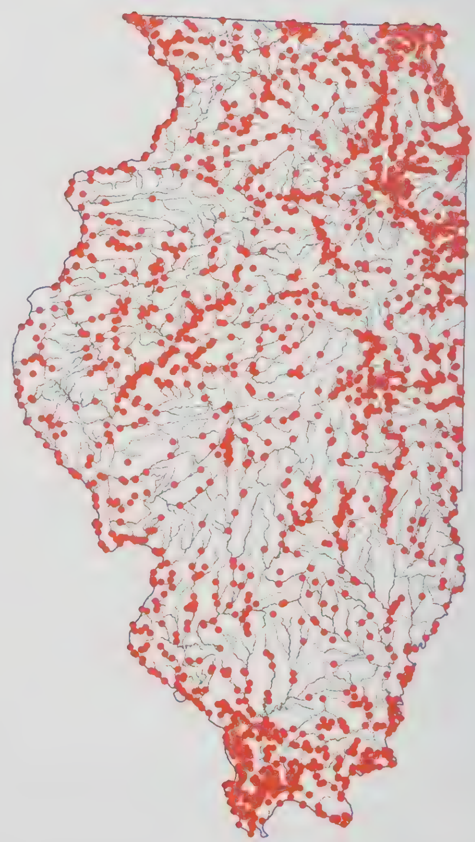

Figure 9.4. Sampling locations of fishes made from 1980 to 2007 in Illinois. From collection data and specimens deposited in INHS and SIUC.

pollution (e.g., sewage runoff, toxic chemicals from industry, pesticide residues, steroid residue from both humans and animals); 6) long-term effects of dams and impoundments; and 7) temperature elevation due to buffer zone reduction and/or stream channelization.

Because of the pervasiveness of agriculture in Illinois, sedimentation (or siltation) is undoubtedly the major cause of stream degradation and has affected at one time or another nearly every stream in the state. The root systems of trees, shrubs, and other vegetation found on stream banks function as anchors for soils while the rerestrial vegetatoin filters runoff in watersheds. The removal of these vegetation buffer zones to the edge of the stream bank has been a major cause of severe soil erosion and ultimately a change in substrate and water clarity for most streams. Sediment loads negatively affect stream organisms by clogging their gills and preventing effective oxygen exchange. High turbidity (silt suspended in water) for prolonged periods results in the suffocation of many aquatic organisms—plants as well as animals. When the primary producers (plants) and primary consumers (e.g., many insect larvae) are eliminated, fishes and other organisms dependent on them for food die or perhaps produce fewer offspring, and eventually fish populations are impacted. Substrates overlain with silt and dense sediment are unsuitable as a spawning substrate for most fishes because eggs laid in such places are unable to obtain an adequate oxygen supply. Fishes also commonly lay their eggs between gravel and rocks or among plants to hide them from predators. Silted-in substrates deprive fishes of that resource.

The drainage of wetlands and bottomland lakes that serve many fishes as nurseries and some stream-dwelling fishes as overwintering refuges and spawning areas is a second major factor in the loss of aquatic biodiversity. These lakes and wetlands in their natural state are among the most productive aquatic systems in North America. In Illinois, most of these lakes were found along large rivers such as the Mississippi and Illinois. Their loss resulted from drainage to produce more farmland and from filling with silt as sediment-laden rivers overflowed during periods of flooding. Artificial (human-made) wetlands, ponds, and small lakes are now very common in Illinois, but most such water bodies are stocked with sportfishes and do not have the ecological value of natural systems.

As more water is used in Illinois, primarily for agricultural purposes and increasing rates of urbanization, water tables are lowered in many places and stream desiccation has become a major problem. Many springs that were formerly perennial are now ephemeral, and populations of fishes restricted to springs disappear during periods of drought. Smith (1, 3) recorded the loss of populations of several species due to loss of spring flow and drought.

Detrimental interactions between exotic and native fishes include competition for resources, predation, hybridization, and the subsequent swamping out of native species genomes, disease, and parasitism. Familiar examples include the Asian carps and the Round Goby (see Chapter 12). Unfortunately, all of the interactions noted have been documented in Illinois fish populations. Simply put, the detrimental effects of non-indigenous fishes certainly outweigh their economic value (see below) or any intrinsic aesthetic value.

Stream pollution has been extensively documented in Illinois (e.g., 5) and continues to be studied at an accelerated pace, in part because the Clean Water Act has been federally funded and is not dependent on the vagaries of state funding. In brief, pollutants (e.g., heavy metals, pesticide residues, runoff from abandoned coal mines, etc.) poison aquatic animals. Major progress has been made in reducing point sources of pollution by the U.S. and Illinois Environmental Protection agencies, but such non-point sources as agricultural runoff of pesticides continue to be persistent problems. The startling accounts of steroids (e.g., those used on cattle for growth and by humans for birth control) found in water today are alarming. Even well-known species of sport fish such as Smallmouth Bass (*Micropterus dolomieu*) are being masculinized or feminized from steroids or chemicals from industrial effluents that mimic hormones in our waters.

Dams and impoundments convert large segments of flowing water into standing water. A few species are favored by the conversion, but many more are eliminated. The pre-impoundment list of species present in a medium to large river in Illinois commonly includes 30–40 species of fishes. In contrast, an impoundment typically supports only 8–12 species of fishes. The negative impact of an impoundment on biodiversity is compounded by the fact that species in the impoundment are common, for example, Largemouth Bass (*Micropterus salmoides*), Gizzard Shad (*Dorosoma cepedianum*), and Common Carp (*Cyprinus carpio*); the species declining in Illinois include those on the threatened and endangered list. Exacerbating the negative impacts of impoundments on biodiversity is their tendency to fill with sediments carried by streams flowing into them. Because they fill in, they are short-lived relative to the potential life of a stream. Dams negatively affect stream communities in addition to the direct effects of inundation. Many species of fishes such as Paddlefish (*Polyodon spathula*) and Blue Sucker (*Cycleptus elongates*)migrate upstream to spawn; when a dam blocks their passage, they cannot reach suitable spawning areas. In a relatively short time populations decline and sometimes disappear.

Temperature pollution, either through the release of coldwater from the bottoms of large reservoirs into streams or temperature elevation from the removal of riparian vegetation along streams, has impacted fish populations. With direct sunlight for prolonged periods, the water is warmed and becomes unsuitable for many species. Another cause of warming is the lowering of the water table, with the result that less groundwater reaches surface streams. Fishes that generally prefer cool water and are adversely affected by this warming trend include trouts, nearly absent from Illinois, and sculpins, which are becoming less common and more restricted in distribution.

Channelization converts streams from a series of riffles and pools of varying characteristics into a ditch of nearly uniform width, depth, velocity, and substrate (see Chapter 5). Instead of providing a variety of habitats, a channelized stream offers essentially only one habitat and only those species capable of living in that habitat persist. In

addition, bankside vegetation is usually removed to enable the large equipment needed for channelization to gain access to the stream. Loss of vegetation, as discussed above, further reduces biodiversity.

OVERVIEW, COMMUNITY TYPES, AND COMMUNITY LEVEL CHANGES

Native to Illinois are 28 families of fishes, about 77 genera, and 192 species (Table 9.1). Since the most recent overview of Illinois fishes (9), five species have been discovered as new to the state, a cyprinid, the Redside Dace (*Clinostomus elongatus*) from extreme northern Illinois near the Wisconsin border (49); a percid, the Fringed Darter (*Etheostoma crossopterum*) from streams in the lower Cache River drainage (10) in southern Illinois; and a topminnow, the Northern Studfish (*Fundulus catenatus*) from southwestern Illinois. The latter species was included by Smith (3) but considered to be in Illinois only as a waif. In addition, we now recognize the Longear Sunfish (*Lepomis megalotis*) (Fig. 9.5) and Northern Sunfish (*Lepomis peltastes*) as separate species. Waldham et al. (11) make a compelling case based on genetic data that the Sea Lamprey (*Petromyzon marinus*) is indigenous to Lake Ontario and has been in the Great Lakes system for about 8,000–12,000 years. We accept their conclusions and consider the Sea Lamprey indigenous to Illinois.

The diversity of fish communities in Illinois is due in large part to the diversity of land-forms and environments found in the state (see Chapter 2). In the following sections we present overviews of the various types of fish communities found in Illinois and discuss the types of changes those communities have experienced in the past 130 years. However, before we can discuss those communities and changes a brief mention is needed of how the field methods used to sample fishes have changed over time.

During the Forbes and Richardson era of statewide fish sampling (Fig. 9.1), most field workers relied on the use of large seines, hook and line angling, and passive fishing techniques (i.e., traps, netting materials of varying mesh sizes set using boats or wading). By the time Smith began his studies, fish sampling involved not only the traditional methods of seining (Fig. 9.6) and netting, but also the widespread use of ichthyocides (i.e., fish poisons developed from neotropical plant compounds and sodium cyanide) and electric seines (12). Near the end of Smith's collecting, large-boat electrofishing had been introduced and was being used in reservoirs and large rivers, primarily as a method for sampling sportfish populations. Since the 1980s, all of these sampling methods have continued in use, although ichthyocides have been largely stopped in stream sampling (although still in use for small farm ponds). Back-pack electrofishing (Fig. 9.7) in small streams is in widespread use, and small-mesh trawls are either now being dragged behind boats in medium to large rivers or pulled by hand. The variety of sampling techniques available to the field worker today is far more diverse than those available a century ago. This disparity can bias the comparisons and is taken into account in our analysis and discussions of fish communities that follow.

NOTABLE EXTANT FISH COMMUNITIES

Illinois, the lowest in elevation of the north-central states, is well watered. After glacial ice fronts melted and receded (see Chapter 2), a number of significant aquatic environments were available for colonization, dispersal, and the establishment of sustainable populations of fishes. Some of the most distinctive fish communities in Illinois can be classified by large-scale features and include: 1) Lake Michigan Fish Community; 2) Big River Fish Community; and 3) Widespread (or Statewide fishes) Fish Community. Some distinctive communities characterized by a smaller number of indicator fish species include: 4) Glacial Lakes Fish Community; 5) Northern Fish Community; 6) Lowlands Fish Community; and 7) Shawnee Hills Fish Community. These communities are separated by fairly narrow transition zones rather than sharp boundaries, except perhaps those species characteristic of big rivers or restricted to Lake Michigan. Abiotic factors play a strong role in fish distribution and community structure and include such parameters as substrate type (e.g., gravel, sand, organic debris), depth, and current velocity. It is common for some fishes (e.g., Rainbow Darter, *Etheostoma caeruleum*) to be found only in shallow, gravel-bottomed riffles with fast current. The Bantam Sunfish (*Lepomis symmetricus*) is typically restricted to medium-depth bottomland lakes and swamps over organic debris. All Illinois fishes have their own habitat and niche requirements, and these can vary seasonally and over a period of years (e.g., larval fish habitat versus that of adults). A few fishes have unusual ranges in Illinois that do not allow for simple categorization. Some are found commonly in northern and southern Illinois but are uncommon or absent from the central part of the state. Others are sporadic and occur only where suitable habitat is available. Some examples include the Central Mudminnow (*Umbra limi*), Slender Madtom (*Noturus exilis*), Southern Redbelly Dace (*Phoxinus erythrogaster*) (Fig. 9.8), and Northern Hogsucker (*Hypentelium nigricans*). Finally, our fish community divisions are based on our own collective experience (about 70+ years) of sampling fishes throughout Illinois and much of temperate North America as well as earlier analyses (13, 14) that allow for large-scale faunal comparisons.

Lake Michigan Fish Community

Fishes restricted to the shores and depths of Lake Michigan have previously been lumped with assemblages from the DuPage River, Chicago canal system, and the Lower Des Plaines River (1, 15). Especially characteristic of Lake Michigan *sensu stricto* are the Sea Lamprey, Lake Trout (*Salvelinus namaycush*), Lake Whitefish (*Coregonus clupeaformis*), Bloater (*Coregonus hoyi*), Round Whitefish (*Prosopium cylindraceum*), Lake Chub (*Couesius plumbeus*), Ninespine Stickleback (*Pungitius pungitius*), Fourhorn Sculpin (*Myoxocephalus thompsoni*), and Slimy Sculpin (*Cottus cognatus*). All of these species persist in Lake Michigan (15) despite both commercial and sport fishing pressure for the salmonids and predation-competition from a rather large and successful group of non-indigenous fishes now established in the lake. Some salmonids probably historically present—Cisco (*Coregonus artedi*), Blackfin

Cisco (*Coregonus nigripinnis*), and the Spoonhead Sculpin (*Cottus ricei*)—appear to be extinct or too rare for detection. About 6% of the indigenous Illinois fish fauna is found only in Lake Michigan.

To enhance the fishery of Lake Michigan and placate both commercial and sport fishers, several fishes have been introduced (see reviews in 15, 16): the Alewife (*Alosa pseudoharengus*), Coho Salmon (*Oncorhynchus kisutch*), Chinook Salmon (*Oncorhynchus tshawytscha*), possibly the Pink Salmon (*Oncorhynchus gorbuscha*), and the Threespine Stickleback (*Gasterosteus aculeatus*). Some species, that first appeared and became established in Lake Michigan have now dispersed into the Chicago canal system and are part of the upper Illinois River fish communities. These include the Oriental Weatherfish (*Misgurnus anguillicaudatus*), White Perch (*Morone americana*), and the Round Goby. Lake Michigan has been stocked with Rainbow Trout (*Oncorhynchus mykiss*), Brown Trout (*Salmo trutta*), and perhaps Atlantic Salmon (*Salmo salar*). No other fish assemblage has had its environment and fish community altered as radically as has that in Lake Michigan. While many species originally part of the historical fauna have been resilient and persist, others have been replaced with ecologically similar species that persist on their own or through annual stocking programs.

Big River Fish Community

The mainstem Mississippi River borders the state on its entire western edge, the mainstem Ohio River on the southern extreme, and the mainstem Wabash River for about one-third of the eastern edge. Cutting across the northern third of the state from near St. Louis, Missouri, to Lake Michigan is the Illinois River, a massive channel maintained for commercial navigation, and historically with some of the richest associated wetlands known in the upper Midwest. These rivers and the lower reaches of their major tributaries are inhabited by a distinctive assemblage of about 30 native species (16%). Especially characteristic of the Big River Community are the Shovelnose Sturgeon (*Scaphirhynchus platorynchus*), Paddlefish (Fig. 9.9), Skipjack Herring (*Alosa chrysochloris*), Goldeye (*Hiodon alosoides*), Mooneye (*Hiodon tergisus*), Channel Shiner (*Notropis wickliffi*), River Shiner (*Notropis blennius*), Emerald Shiner (*Notropis atherinoides*), Blue Sucker (*Cycleptus elongatus)*, and Blue Catfish (*Ictalurus furcatus*). Nearly all species in tributaries to the Mississippi River are found, at least occasionally, in the river; 140 native species have been collected in the mainstem of the river (14). In contrast, only about 60 species have been recorded from the mainstem of the lower Ohio River in Illinois. Collections of so many species demonstrates that most fishes in Illinois use big rivers at least occasionally.

Environmental gradients along the Mississippi River explain some of the community structure in the river. Although a number of factors are involved, bottom type, gradient, and turbidity seem to be of fundamental importance (13, 17). The Mississippi River below the mouth of the Missouri River is ecologically transitional between the Missouri and the upper Mississippi, and this is reflected in its fish community. At least six species (Pallid Sturgeon, *Scaphirhynchus albus*, Flathead Chub, *Platygobio gracilis*, Sturgeon Chub, *Macrhybopsis gelida*, Sicklefin Chub,

Table 9.1. Composition of Illinois fish fauna over the past 130 years.

	Total no. species	No. aliens	No. extirpated
Forbes & Richardson (1909)	142[1] (141 native)	1	Not applicable
Smith (1979)	199 (186 native)	13	9
Burr (1991)	209 (187 native)	22	12
2008	214 (192 native)[2]	22[3]	10[4]

1. Forbes & Richardson (4) recognized 150 species, 142 of which are considered valid today.
2. Additions since Burr (9) include Sea Lamprey, Redside Dace, Northern Studfish, Northern Sunfish, and Fringed Darter as indigenous.
3. Changes since Burr (9) include elimination of Rudd, Rio Grande Cichlid (no evidence of reproduction or status unknown, respectively) and Sea Lamprey (see above); and addition of Pink Salmon, Round Goby, and Oriental Weatherfish as established but non-indigenous.
4. Rediscoveries since Burr (9) of species thought to be extirpated include Bigeye Chub, Northern Madtom, Crystal Darter, and Harlequin Darter; Muskellunge may have gone extinct naturally but it is maintained in Illinois and intensively managed. Bloater, Lake Whitefish, Cisco, and Round Whitefish are extant (15).

Figure 9.5. Longear Sunfish, *Lepomis megalotis*, a stream fish widely distributed and abundant in eastern and southern Illinois. Photo by W. Roston.

Figure 9.6. Sampling a wadable stream with a minnow seine. Minnow seines such as this one have been used to sample fishes for over 120 years and will likely continue to be used well into the future given their simple design and effectiveness. Photo by T. Rice.

Figure 9.7. The of use of back-pack electrofishers such as this one is a sampling method that has only recently become available to biologists. Photo by R. Hopkins.

Macrhybopsis meeki, Western Silvery Minnow, *Hybognathus argyritis* and Plains Minnow *H. placitus*) are native to the Mississippi River only below the mouth of the Missouri, where high turbidity, increased current velocity, and shifting sand and silt substrates provide suitable habitat. All of these species are now more common in the swifter and more turbid Missouri River. This community has changed rather dramatically in the past 20 years, and we now recognize all six characteristic fishes as threatened or endangered in Illinois. Three of these species have not been taken in Illinois since the 1980s. The Mississippi River has suffered from large-scale channel modifications created primarily for barge traffic and to control flow, and has been assaulted by the influx of exotic carps to the point that the greatest biomass in the river is composed of four Asian carp species, rather than the native community of buffalofishes, carpsuckers, and catfishes. Other species usually considered characteristic of tributaries are locally common and reproducing in the mainstem of the river both above and below the mouth of the Missouri and include the Freckled Madtom (*Noturus nocturnus*), Western Sand Darter (*Ammocrypta clara*), and River Darter (*Percina shumardi*). The other big rivers bordering Illinois have less diverse faunas and do not have any big-river fishes not also found in the Mississippi River.

Figure 9.8. Southern Redbelly Dace, *Phoxinus erythorgaster*, a small stream species detrimentally affected by drought, spring loss, and the lowering of the water table. Photo by W. Roston.

Figure 9. Paddlefish, *Polyodon spathula*, an ancient fish (known from fossils dating to at least Cretaceous times) characteristic of the Big River Fish Community. Photo by W. Roston.

Widespread Fish Community

About 50% of Illinois' fishes are wide-ranging and occur in all major watersheds of Illinois. Outstanding examples include the Gizzard Shad, Bluntnose Minnow (*Pimephales notatus*), Creek Chub (*Semotilus atromaculatus*), Yellow Bullhead (*Ameiurus natalis*), and Green Sunfish (*Lepomis cyanellus*). The exotic Common Carp, now with us for over 100 years, is found in all streams in Illinois. Although the distributions of species in the other communities are correlated with environmental gradients characteristic of physiographic regions or lacustrine conditions, widespread species are not similarly restricted. In accounting for the distribution patterns of widespread fishes in Missouri, Pflieger (13) assumed that they have broader environmental tolerances than species of more restricted distribution. Many of these species inhabit quiet pools and backwaters of streams. These habitats occur in all regions of the state, and species with broad tolerances for turbidity, bottom type, flow, and temperature are thus provided with a habitat not limited to a specific stream size or a specific region (i.e., Lake Michigan). Lentic, or non-flowing, habitats are common in and along our big rivers and probably facilitate dispersal from one area to another. Some fishes that are widespread also are favored by humans and are probably more widely distributed than formerly. The Channel Catfish (*Ictalurus punctatus*), Bluegill (*Lepomis macrochirus*), and Largemouth Bass are frequently stocked into ponds and lakes. Reservoir construction on major rivers also has increased lentic habitats (14).

Glacial Lakes Fish Community

As Pleistocene glaciers receded, large wetlands and glacial pothole or kettle lakes were created in northeastern Illinois, primarily in Cook, Lake, and McHenry counties. This region has been referred to as the Southeastern Wisconsin Till Plains (see Chapter 2). Many of the wetlands have been filled, and all of the lakes have been affected in numerous ways (e.g., loss of buffer zones, introduction of predatory sport fishes, sewage and chemical runoff, etc.) by urbanization and agriculture. A small but distinctive community of fishes still occupies those lakes that have maintained relatively clear water, a littoral zone with submerged vegetation,

and a firm sandy substrate. Exemplars of the Glacial Lakes Community include the Blackchin Shiner (*Notropis heterodon*), Blacknose Shiner (*Notropis heterolepis*), Pugnose Shiner (*Notropis anogenus*), Banded Killifish (*Fundulus diaphanus*), and Iowa Darter (*Etheostoma exile*). Old records from the Forbes and Richardson and Smith surveys indicate that some of the species (e.g., Blacknose Shiner, Iowa Darter) were more widely distributed, but the community is now largely restricted to the glacial lakes and their outlets. All of these species have been listed as threatened or endangered in Illinois. Fortunately, however, recent studies (i.e., 2000s) indicate that several lakes in the region support stable and sometimes large populations of each of the five species noted (18, 19). Also, artificial lakes function as sanctuaries for these five species (18, 20, 21). This region of Illinois has the fastest growing population in the state; privatization of some of the lakes, the direct removal of submerged vegetation, and the introduction of large predators such as the Muskellunge or Muskie (*Esox masquinongy*) (Fig. 9.10) are continued threats to this community.

Figure 9.10. Muskellunge or Muskie, *Esox masquinongy*, a formerly extirpated species now maintained through successful, but intensive, fish management in selected public and private lakes. Photo by W. Roston.

Northern or Boreal Fish Community

A small (6%) part of the native Illinois fish fauna is mostly restricted to streams in the northern quarter of the state. Most of these species probably had historical origins in cooler climates and exist today in clear, cool streams, usually with firm substrates, and occasionally with submerged vegetation. Exemplars of this community include the Northern Brook Lamprey (*Ichthyomyzon fossor*), Brassy Minnow (*Hybognathus hankinsoni*), Common Shiner (*Luxilus cornutus*), Redside Dace (*Clinostomus elongatus*) (Fig. 9.11), Ozark Minnow (*Notropis nubilus*), Greater Redhorse (*Moxostoma valenciennesi*), Mottled Sculpin (*Cottus bairdii*), Northern Pike (*Esox lucius*), Brook Stickleback (*Culaea inconstans*), and Least Darter (*Etheostoma microperca*).

Lowlands Fish Community

This 9.community comprises fishes that normally have their distributions centered in either the Coastal Plain (or Mississippi Alluvial Plain) physiographic province or the environmentally similar lower Big Muddy River of southern Illinois. These fishes are usually more abundant farther south on the Mississippi Embayment of the Gulf Coastal United States. Especially characteristic of the lowlands are Blacktail Shiner (*Cyprinella venusta*), Cypress Minnow (*Hybognathus hayi*), Bantam Sunfish (*Lepomis symmetricus*), Spotted Sunfish (*Lepomis punctatus*) and Banded Pygmy Sunfish (*Elassoma zonatum*). This community is closely associated with a lack of topographic relief and low stream gradients. They inhabit standing waters or sluggish streams and ditches with bottoms of sand or mud. Many are also found among or near woody debris or submerged aquatic vegetation. This community lives within a relatively small area of Illinois, and four of the species found here are listed as threatened or endangered by the state due to habitat loss or alteration.

Because parts of the physiographic provinces north of the Coastal Plain share aquatic habitats similar to those of the Coastal Plain (especially the floodplains of big rivers), members of the Lowlands Fish Community have dispersed to areas far beyond the Coastal Plain. Common species living on the Coastal Plain south of Illinois, such as the Ironcolor Shiner (*Notropis chalybaeus*), Weed Shiner (*Notropis texanus*), Pirateperch (*Aphredoderus sayanus*), Flier (*Centrachus macropterus*), and Spotted Sunfish (*Lepomis punctatus*) are found far to the north of the Coastal Plain in Illinois. Except for the Pirateperch and Flier, these species are disappearing in Illinois and plans to protect them are being developed.

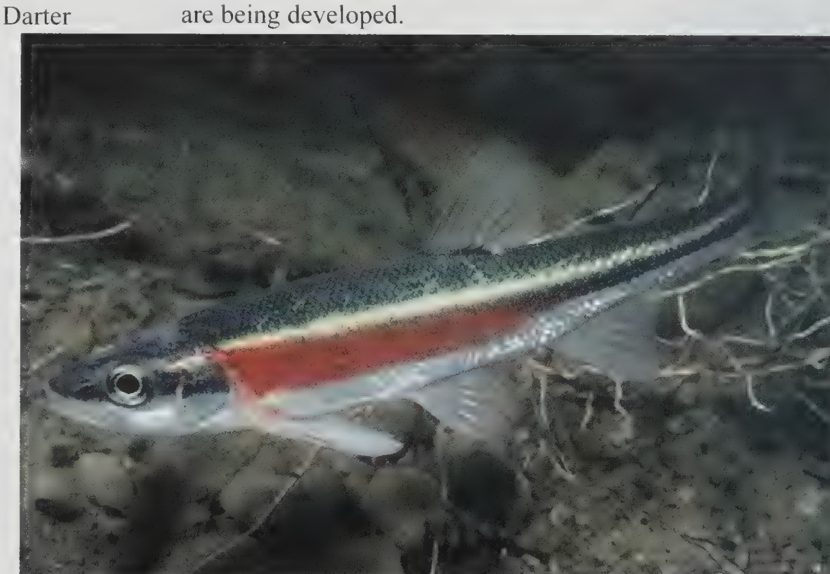

Figure 9.11. Redside Dace, *Clinostomus elongatus*, a recent addition to the indigenous fauna of Illinois and a member of the Northern (or Boreal) Fish Community. Photo by W. Roston.

Shawnee Hills Community

The Illinoian Glacier reached within 30 km of the northern boundary of the Coastal Plain in southern Illinois (22). This unglaciated region of Illinois is characterized by steep hills and valleys and high-gradient streams with gravel and cobble substrates (see Chapter 2). A few fishes have survived for various lengths of time in small Ozarkianlike streams (such as in the southern half of Missouri) in the Shawnee Hills of southern Illinois. An outstanding example is the Spring Cavefish (*Forbesichthys agassizi*) now known from springs, spring-runs, and associated nearby swamps in a narrow strip of upland streams across southern Illinois (23). Adults are strongly associated with karst, elevated springs, and rocky substrates. The Banded Sculpin (*Cottus carolinae*) is primarily restricted to the Shawnee Hills but isolated populations also are known from springs near the middle Mississippi River and the lower Illinois River. The Least Brook Lamprey (*Lampetra aepyptera*) (Fig. 9.12) is restricted to Shawnee Hills streams (24). The Spottail Darter (*Etheostoma squamiceps*) and a close relative, the Fringed Darter, occupy only streams in either the eastern or western Shawnee Hills, respectively (10, 25). The Stripetail Darter (*Etheostoma kennicotti*) and Cypress Darter (*E. proeliare*) occur only in the Shawnee Hills, although the latter species is occasionally found on Coastal Plain streams just south of the Shawnee Hills (26). The Scarlet Shiner (*Lythrurus fasciolaris*) once occurred in Big Creek in the eastern Shawnee Hills, but has not been seen since 1900, and is presumed exterpated. Overall, this community (4% of the indigenous fauna), though narrowly distributed in Illinois, appears to be stable, particularly in protected areas of the Shawnee National Forest. Only the Least Brook Lamprey is recognized as threatened in this extreme southern Illinois fish community.

STATEWIDE THREATS AND CHANGES

ALIEN COMPONENT

With the possible exception of population declines due to habitat alteration, exotic species represent the greatest change to the Illinois fish fauna. When Forbes and Richardson (4) published the first statewide survey of Illinois fishes, they recorded 141 native species and only one exotic, the Common Carp. Smith (3) and his associates, with much greater effort in poorly sampled areas (e.g., mainstem Mississippi River, Lake Michigan), a modern highway system, and new sampling techniques, found 186 native fish species, and the number of non-indigenous species had increased by 12. By 1996, a few more exotics (Round Goby, Oriental Weatherfish, *Misgurnus anguillicaudatus*, Silver Carp, *Hypophthalmichthys molitrix*) were established and spreading rapidly (16). Today, the number of non-indigenous fishes established (i.e., reproducing) or occurring as regular annual visitors (i.e., Striped Mullet, *Mugil cephalus*) add five families, 12 genera, and 22 species to the Illinois fauna (Table 9.1). A looming threat comes from the exotic Black Carp, *Mylopharyngodon piceus*, a molluscivore native to Asia, known now from two large adults (27) collected in the Mississippi River floodplain of southern Illinois. This species is established in a few southern states and has the potential to reduce native mussel and snail populations in Illinois if it were to become established. The exponential increase in Illinois of Silver Carp and Bighead Carp (*Hypophthalmichthys nobilis*) populations (28), two large-river, filter-feeding cyprinids from Asia, threatens native and truly unique fishes such as the Paddlefish, also a large-river inhabitant and filter-feeder. Entrepreneurial commercial fishers have taken advantage of the abundance of Asian carps in Illinois waters; one company on the Illinois River sold 2 million pounds of carps in 2005 to 20 markets across the United States (29).

An electric weir (barrier) was established in 2002 in the Chicago Sanitary and Ship Canal that connects Lake Michigan to the Illinois River to stop the spread of Asian carps into Lake Michigan and the dispersal of the Round Goby from Lake Michigan to the Illinois River and, ultimately, the rest of the Mississippi River basin. By 2007, the Round Goby had breached the weir and moved into the Illinois River (30). It now is found south of Peoria on the Illinois River! Bighead and Silver carps are very near the barrier having dispersed upstream in the Illinois River to above the mouth of the Kankakee River (Fig. 9.13).

EURYHALINE FISHES IN ILLINOIS WATERS

While not surprising that non-indigenous fishes have become purposefully or accidentally established in Illinois, what might be more unexpected is the establishment or regular annual visitation of Illinois waters by what most people would consider marine or estuarine fishes (those occurring at the interface between fresh and salt water). These fishes are usually defined as euryhaline species since they can tolerate a wide range of salinities. Minckley and Krumholz (31) reported the first records of the Threadfin Shad (*Dorosoma petenense*) in the Ohio River, collected in 1957. Previously, this species was known only from southern states, Mexico, and estuaries along the Gulf Coast. By the beginning of the twenty-first century, Threadfin Shad were common in the lower Ohio, lower Wabash, middle and upper Mississippi rivers, and the lower reaches of a few major streams (e.g., Illinois River) (16). Subsequent to its natural arrival, the species has been introduced as forage for sport fishes in a number of reservoirs in southern Illinois.

In a footnote, Smith (3) recorded the first Illinois individual of the Inland Silverside (*Menidia beryllina*) from the middle Mississippi River and, by the middle 1990s, this fish had spread rapidly in the lower Ohio River, the middle Mississippi River, and the lower reaches of major tributaries (e.g., Big Muddy River) (32). This species previously was known from marine and brackish waters on the Gulf Coast and the lower Mississippi River. Like the Threadfin Shad, the Inland Silverside has been introduced as forage for sport fishes in several reservoirs in southern Illinois. The mainstem river records are considered to be the result of more southern populations spreading northward in the Mississippi and Ohio rivers, and the species is established in Illinois. By 1989, another familiar resident of estuaries, salt marshes, and shoreline areas of the Atlantic and Gulf coasts (Striped Mullet) started to appear in the lower Ohio and Middle Mississippi rivers (32). Since that year specimens,

Figure 9.12. Least Brook Lamprey, *Lampetra aepyptera*, Lusk Creek, Illinois. A threatened species characteristic of the Shawnee Hills Fish Community. Photo by B. Fink.

photographs, and reliable reports of large schools of this species in the bordering rivers have come to light. Because this species apparently does not spawn in fresh water, it is likely a regular annual visitor of major Illinois waterways.

In 1990 and again in 2006, the Atlantic Needlefish (*Strongylura marina*) was taken from the lower Ohio River on the Kentucky side of the river. This species occurs along the Atlantic and Gulf coasts and occupies fresh water rivers in all the states bordering the coastlines. It has spawned far upstream in the freshwater rivers of Alabama and has dispersed through the Tennessee-Tombigbee waterway into Kentucky Reservoir, Tennessee (33). We predict that this species soon will spread into the middle Mississippi River of Illinois and Missouri.

Other fishes, formerly considered as marine, estuarine, or brackish water inhabitants, have dispersed into Illinois waters, but primarily through the St. Lawrence River-Great Lakes region. These include the Rainbow Smelt (*Osmerus mordax*), the Alewife (*Alosa pseudoharengus*), and the White Perch (*Morone americana*) (34). All of these species are established and reproducing in Illinois, and the White Perch and Rainbow Smelt have spread through the Chicago canal system into the Illinois and Mississippi rivers. One obvious conclusion that can be drawn from several of these examples is the potential for rapid dispersal by fishes, some covering hundreds of river miles and acres of lakes within a short time.

It has been speculated (e.g., 32) that recent changes in water levels of the Mississippi River (including an extreme 100-year flooding event and several droughts) have created water-quality conditions (perhaps more dissolved solids) favorable for mullets, silversides, shads, needlefishes, and other euryhaline fishes to reach the middle Mississippi River. In the last decade, two blue crabs (genus *Callinectes*) also have been collected in the lower Ohio River. Their method of dispersal is likely to be different (e.g., hanging on the sides of barges), than that of the fishes, but their occurrence in fresh water is presumably a part of the modification that has occurred in our waterways in recent decades.

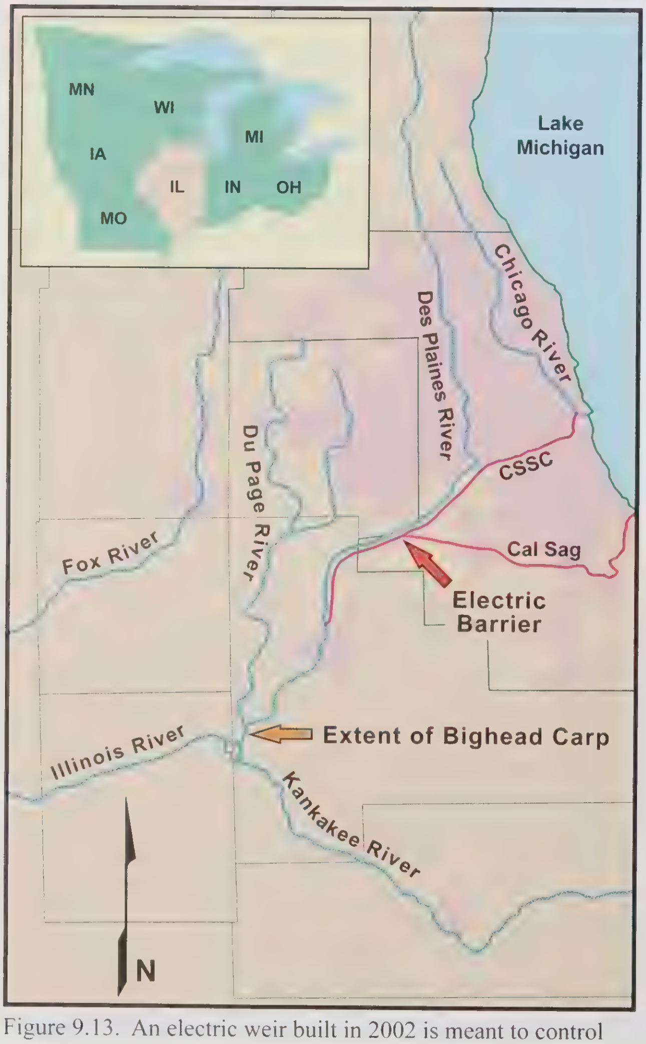

Figure 9.13. An electric weir built in 2002 is meant to control passage between the Great Lakes and Mississippi River, via the Illinois River.

NEOTROPICAL FISHES IN TEMPERATE ILLINOIS

Tropical fishes have been reported from Illinois waters for over 15 years. These species originate in Central or South America where they function as food or forage fish. All records of neotropical fishes in Illinois, which are either specimens vouchered into museum collections or newspaper articles (usually with photographs), are almost certainly the result of aquarists releasing their pet fishes. All of these species are commonly sold by pet shops in Illinois and surrounding states and include the Pirapatinga (*Piaractus brachypomus*), Red Piranha (*Pygocentrus nattereri*), Redtail Catfish (*Phractocephalus hemioliopterus*), Vermiculated Sailfin Catfish (*Glyptoperichthyes disjunctivus*), Raphael Catfish (*Platydoras costatus*), and the Oscar (*Astronotus

ocellatus). We do not consider any of these species as permanent members of the Illinois fish fauna, but the Pirapatinga continues to be captured and reported from municipal ponds, Hennepin Canal in northwestern Illinois, power-cooling lakes (e.g., Powerton Lake), and lakes associated with large public universities. Because the herbivorous Pirapatinga strongly resembles some species of piranha (e.g., Red Piranha), the capture of specimens by anglers often is reported in newspaper accounts and causes undue alarm among swimmers and boaters. Possible establishment of a piranha species in a power-cooling lake (e.g., Lake of Egypt) that stays relatively warm throughout the year could cause a very real ecological and social disaster.

EXTIRPATION AND RARITY

Extirpation from Illinois waters has also brought about significant changes in fish communities. The losses of fishes have been across many taxonomic groups and trophic and reproductive guilds. Approximately 10 species apparently are extirpated including a lamprey (family Petromyzontidae), a gar (Lepisosteidae) (Fig. 9.14), at least two whitefishes (Salmonidae), two minnows/shiners (Cyprinidae), a sculpin (Cottidae), and three darters (Percidae). A few species that were once considered extirpated have been rediscovered, but are extremely limited in range and abundance. These include, the Crystal Darter (*Crystallaria asprella*) (35), Bigeye Chub (*Hybopsis amblops*) (32, 36), Harlequin Darter (*Etheostoma histrio*) (32), and Greater Redhorse (37). It is also noteworthy that some extirpations occurred probably long before the Smith (3) survey and perhaps before widespread deforestation and the agrarian lifestyle dominated the Illinois landscape. Page and Retzer (38) reviewed the status of Illinois' rarest fishes and included 10 species in five families. Some of these (e.g., River Chub, *Nocomis micropogon*, Taillight Shiner, *Notropis maculatus*, Northern Madtom, *Noturus stigmosus*) are on the edges of their natural ranges, but others (e.g., Weed Shiner, *Notropis texanus*) have relict populations in Illinois or have disappeared from several major drainages throughout the state (e.g., Pallid Shiner, *Hybopsis amnis*). The only federally endangered fish species in Illinois is the Pallid Sturgeon (*Scaphirhychus albus*). The Pallid Sturgeon, known from the lower Mississippi River, is highly threatened by the caviar industry and commercial fishers. A few species seem to have disappeared in the past decade from the middle Mississippi River. These include the Flathead Chub (*Platygobio gracilis*), Western Silvery Minnow (*Hybognathus argyritis*), and Plains Minnow (*Hybognathus placitus*). Annual surveys conducted by the Illinois Department of Natural Resources on the mainstem Mississippi River have not found these three species since the late 1980s. The number of extirpated and rare (threatened or endangered) fishes accounts for about 21% of the native fauna. All of the above species have disappeared or are so rare that detection with standard sampling techniques has revealed no or only a few records.

In another category of rarity are those fishes that use Illinois waters for migratory purposes (e.g., Alabama Shad, *Alosa alabamae*), feeding, and growth (American Eel, *Anguilla rostrata*) or have some sport-fishing value despite original extirpation (i.e., Muskellunge). The anadromous (fishes that live in marine habitats but migrate into freshwater to spawn) Alabama Shad used the Mississippi River to reach habitats appropriate for reproduction even though there are no known spawning populations reported from Illinois; a nearby population in Missouri is known to breed there (39). The American Eel (*Anguilla rostrata*), the only catadromous (fishes that live in freshwater habitats but migrate to the ocean to spawn) fish species in Illinois is encountered far less frequently than it was when Smith (3) completed his survey. It has been considered for federal listing, especially after recent surveys in Atlantic Coast streams revealed significant extirpation; however, more

Figure 9.14. The Alligator Gar (*Atractosteus spatula*), a species known to reach lengths of almost 10 feet, is likely extirpated from Illinois due to the drainage of floodplain habitats along the Illinois and Mississippi rivers and the channelization of those rivers. Photograph courtesy of the American Museum of Natural History.

recent data do not support listing. Most Illinois records date from the 1960s and 1970s; however, single specimens were collected from the Rock River in 1998 and the Ohio River in 2001. *Anguilla* may now be restricted just to the large bordering rivers (middle Mississippi River, lower Ohio River, lower Wabash River), where it is rarely captured.

Finally, the Muskellunge or Muskie (Fig. 9.10), once known from Lake Michigan (3, 4), but probably extirpated over a century ago, now exists year-round through stocking in Lake Kincaid, Jackson County, Lake Shelbyville, Shelby/Moultrie counties, some of the glacial lakes, Lake County, and many private lakes. The Kincaid and Shelbyville reservoir populations are large, and support a successful sport fishery.

With this example and others (e.g., Brook Trout, *Salvelinus fontinalis*), it is more accurate to state that about 25% of the native Illinois fish fauna has either disappeared from state waters, is threatened or endangered, or is maintained now only through costly sport fish management programs.

UNSOLVED TAXONOMIC ISSUES

Beginning in the late 1800s and continuing through today, there have been intense studies of the basic taxonomy, geography, species recognition characters, nomenclature, and other endeavors to help clarify the diagnostic features used to distinguish fish species in Illinois. Much of this information has been summarized in Page and Burr (40). Illinois still has its share of taxonomic problems with fishes. Some taxonomic changes would add more species to the state's list of native species and others would reduce the number. For example, the Mimic Shiner (*Notropis volucellus*) and the Channel Shiner (*Notropis wickliffi*) are two very similar species, the latter apparently only found in big rivers and was recognized as a distinct species only recently (41). Characters used to distinguish these two phenotypes in Illinois are variable and are apparently not diagnostic elsewhere. Blacktripe and Blackspotted topminnows (*Fundulus notatus* and *F. olivaceus,* respectively), where their ranges overlap and apparently interbreed and can be difficult to distinguish even when they don't overlap. Especially difficult in Illinois are samples from the Big Muddy and Cache rivers

RANGE EXPANSIONS

In most of Smith's writings regarding the Illinois fish fauna, he emphasized the losses and declines of species that were apparently stable during the Forbes and Richardson surveys. However, Smith also noted the expansion of certain species in Illinois. An outstanding example is the Red Shiner (*Cyprinella lutrensis*), a primarily western fish that is now nearly statewide in occurrence. Since the Smith era, we have documented the spread of several species. The Dusky Darter (*Percina sciera*) has spread into small tributaries of the Ohio River in southern Illinois. The Bullhead Minnow (*Pimephales vigilax*) is now abundant in the Cache River of southern Illinois, where Smith had only one record from near the mouth of the river. The Channel/Mimic Shiner was very uncommon in the Mississippi River mainstem during Smith's survey but is now the most abundant cyprinid there (42). The Spottail Shiner (*Notropis hudsonius*) has become more common in the middle Mississippi River.

A FUTURE ILLINOIS FISH FAUNA

Illinois is a well-watered, mostly flat, state that is centrally located geographically. Its great length and variety of aquatic systems (e.g., big rivers, large lakes, wetlands, swamps, springs, and small streams) account in large part for its fish diversity. In this chapter we have briefly synthesized the history of our knowledge of native and non-native fish diversity and recognized what we believe are the large-scale communities that make up a reasonably stable state fish fauna.

Collections made by Forbes and Richardson spanned the years 1876 to 1903, although the peak collecting years were between 1892 and 1901, including at least 184 collections in 1900 alone (Fig. 9.2) (43). The bulk of Smith's field work and that of his associates began in 1958, peaked in 1968 (351 collections), and continued through the 1970s (Fig. 9.2). From 1980 to 2007 over 2,880 collections throughout Illinois were made (Fig. 9.2), with peak years of collecting from 1997 to 2000. Interestingly, Smith made a total of 3,128 collections over a shorter time period. There have been extensive collecting efforts in other north-central states (e.g., Wisconsin, Michigan, Ohio), but none that span the time period in Illinois. We expect that Illinois will continue to be sampled on a statewide basis into the future especially because fish community structure is now a major part of indices used to assess water quality and stream use.

THE PROPHECY

In about 130 years researchers have recorded 192 native fish species, but at least 10 (5%) of these are almost certainly extirpated in Illinois waters. During this same time period we have gained over 20 species new to Illinois through introduction by humankind or by natural dispersal from estuarine environments. We may gain more species through pet releases and aquaculture (44). Given an estimated future extinction rate of 2.4% per decade for freshwater fauna in the United States (45), about 10% of the indigenous Illinois fish fauna could be exterpated by 2050. The prevention of this loss will be largely contingent on societal will to implement effective conservation actions.

It is difficult not to over emphasize the significance of the alien component and its long-term effects on fish communities. The Asian carp examples clearly demonstrate that eradication is now well beyond our reach and that these "new" community components are dominant species in some communities in terms of biomass. Even monumental commercial fishing efforts seem to be having little effect on the spread and dominance of this group of fishes. In about 10 years the Round Goby and Oriental Weatherfish may be major components of the Mississippi River system. The Round Goby has had a dramatic effect on the original Lake Michigan fish community, particularly through its aggressive nesting system and predation. Native sculpins can hardly compete. An angler on the Illinois River now has a much better chance of catching an Asian carp than a Largemouth Bass or White Crappie (*Pomoxis annularis*). Unfortunately,

the exotic fish introductions are permanent and ineradicable. The average angler and resident of Illinois has little interest in these species for food, and markets have developed almost exclusively among communities of international residents from Southeast Asia.

HOMOGENIZATION

Rahel (46) pointed out that fish faunas across the United States have become more similar through time because of introductions of "cosmopolitan" species, especially those intended for use in food or sport fishing. The northeastern and western states have received the most introductions and thus have been more homogenized (in terms of fish diversity) in the last 150 or so years. While Illinois has had stockings of sport fishes, most of this activity has been restricted to reservoirs and farm ponds. Illinois' native fish diversity is several times that of the west or New England states and has so far not been dramatically affected by sport fish management except in localized areas (reservoirs, power-cooling lakes, farm ponds) where sport fishes dominate and are intensely managed. Dam building and the inundation of flowing waters has had a greater effect than introduction of sport fishes on fish communities because of loss of habitat heterogeneity.

RESILIENCY OF FISHES

Surrounding states (i.e., Wisconsin, Iowa, Missouri, Indiana, Kentucky) have suffered exterpations of native fishes and introduction of non-indigenous fishes similar to Illinois. The trends in losses or increases in richness are dynamic (7) and have been compared mostly at the drainage level. While losses in richness are often the major conclusion in studies of fish faunas over time, one of the long-term trends appears to be a pattern of resiliency. Fish species such as the Bigeye Chub or Crystal Darter that we were convinced were extinct in Illinois are still present in state waters. The Bigeye Chub recently has been found in several Wabash River tributaries where abundance figures indicate the species is recruiting and reproducing in Illinois once again (Trent Thomas, IDNR, pers. comm.). This is a positive pattern and may indicate the improvement of overall water quality in Illinois (47), our statewide efforts to control erosion, and the fact that more highly trained fisheries personnel are thoroughly sampling stream reaches for all fish species, not just those considered to be of commercial or sport value.

SUMMARY

Our review has shown that 214 fish species, in 89 genera, and 33 families now occur or did occur in Illinois waters. We have an excellent data-base of state wide collections (Figs. 9.1–9.4) that allows for comparisons in abundance and richness of the communities we have described for the state. In view of the major changes to aquatic environments in the past 100 years, the fish fauna of Illinois has demonstrated remarkable resilience. We have lost only 10 fish species or 5.2% of the native fauna because of the large number of environmental changes that have occurred over an approximately 130-year period of recorded history. However, as climate change and other environmental perturbations continue, the changes in fish communities in the near future are likely to be more severe and negative than those to date. This is particularly true in the middle Mississippi and other large rivers and Lake Michigan, where ship canal maintenance, raw pollution, and urbanization will progress for decades. The trend in establishment of exotic fishes will also probably continue and more native species will go extinct or experience population declines due to their interactions. The question still remains, "how do we as fisheries and aquatic resource professionals make the public, politicians, and policy makers hear the critical biological signals of water resource degradation amid the noisy chaos of short-term economic gain and unsustainable development (48)?" The changes that aquatic biologists have detected over 13 decades, including the discovery of species once thought to be extirpated or the collection of new invasive species, offers a strong argument for the continued monitoring of fish communities in Illinois.

DEDICATION

To the memory and career of Dr. Philip Wayne Smith, a life-long naturalist and our graduate advisor and teacher.

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CHAPTER 10

Aquatic Macroinvertebrate Assemblages in Illinois: Diversity, Changes, and Prospects for the Future

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OBJECTIVES

This chapter presents an overview of several aquatic macroinvertebrate assemblages that occur in Illinois, discusses the ability of the state's waters to support them, points out known losses within particular assemblages, discusses important improvements in water quality, and briefly considers what the future holds for macroinvertebrates in the state. While numerous other groups of invertebrates occur in Illinois, not all can be covered in a single chapter. Those discussed in this chapter represent groups that have received greater attention from past and present biologists at the Illinois Natural History Survey (INHS) and other institutions.

INTRODUCTION

Rivers, creeks, lakes, and marshes are universally appealing to humans. They have for years brought out the poets, artists, adventurers, and romantics in many of us. These aquatic habitats provide water for commerce and industry and serve as a method of transportation. They also provide water for consumption, food production, and recreation. These latter uses rely on relatively clean sources of water. Many people link the health of the water to its ability to support fish, birds, and other vertebrate wildlife. However, beneath the surface exist dynamic communities of organisms that go unnoticed by many. In these communities, one finds a tremendous variety of invertebrates that in large part are sustaining the vertebrates that are much more visible.

Aquatic macroinvertebrates are defined as organisms without backbones that live at least a portion of their lives in water, and are large enough to be seen with the naked eye (Fig. 10.1). They are important because they form a critical link between the plants and microbes that they consume and vertebrates that eat them. The lowest level of any freshwater food web is made up of energy sources such as algae, leaves, and wood that fall into the water, and the bacteria and fungi that grow on organic and mineral surfaces. Macroinvertebrates are adept at consuming these food resources and converting them into animal protein, thus serving as the conduit of energy between trophic levels in aquatic habitats (1). For example, common midwestern sport fishes such as bass and sunfish consume up to two-thirds of the annual production of crayfishes in streams, an amount that constitutes a major component of their diet and serves as the fuel for those fisheries (2).

Aquatic macroinvertebrates are also invaluable in that they often are used as indicators of water quality. For example, some macroinvertebrates, mostly insects, can tolerate low oxygen concentrations and become more abundant than those species that cannot. The introduction of untreated or poorly treated sewage or livestock waste into water bodies provides organic matter that bacteria consume, and in the process use large amounts of oxygen. Through monitoring macroinvertebrate assemblages in a stream or lake, one can detect whether a water body has been altered by some pollution event or other disturbance.

A third important aspect of freshwater macroinvertebrates is their function in ecosystems. Scientists are starting to recognize that many of them are highly imperiled and that their loss could permanently impair the health of aquatic ecosystems. In addition to the direct impacts of changes that occur to habitats within stream channels or lake-beds, the quality of aquatic habitats is at the mercy of land-use practices on the lands they drain. These practices are generally variable and their effects are multiplied as drainage basin size increases. The cumulative nature of these effects contributes to the greater extinction rates and levels of imperilment generally observed in aquatic organisms compared to terrestrial ones (3), and the rate of loss is predicted to be sustained or even accelerated in the future (4). Estimates based upon recent data indicate that as many as 10% of the nearly 100,000 species of aquatic invertebrates worldwide may have already been lost (5). In North America, it is macroinvertebrates (stoneflies, crayfish, and freshwater mollusks) not vertebrates or plants, that have taken the dubious honor of being most imperiled (6). Locally, Illinois researchers have documented extinctions, extirpations, and range losses for many macroinvertebrate species inhabiting, or formerly inhabiting, Illinois waters (7, 8).

THE MACROINVERTEBRATE ASSEMBLAGE IN ILLINOIS: AN OVERVIEW

Illinois is at the crossroads of two major biomes, that of the eastern deciduous forest and the central tallgrass prairie (see Chapter 4). It is a long state, extending almost 400 miles north to south and nearly five degrees of latitude, providing varied climatic and vegetation zones. Its nexus among three great rivers, the Mississippi, Ohio, and Wabash, provided pathways for aquatic species into the state from a number of directions. Its glaciated past (see Chapter 2) has ensured that the species living in Illinois are mostly newcomers geologically, but unglaciated areas in the south and the northwest corner of the state have provided refugia for aquatic species even during the coldest times. All of these influences have led to a diverse array of macroinvertebrates taking residence in Illinois.

Yet recent, dramatic changes in the landscape have reshaped our natural heritage. Historically, Illinois was up to 55% tallgrass prairie with the remainder being largely forested (see Chapter 4). The prairies have been almost completely converted to row crops and cattle pasture, with only about 0.01% of the original prairie remaining. Forests have also dropped from a high of 42.4% of land cover to the current 14.6%. These habitat modifications have contributed to drastic changes in the range and presence of many species in the state, aquatic macroinvertebrates included. We are fortunate that INHS researchers sought to preserve the knowledge of the distribution of plants and animals through the deposition of millions of specimens into various INHS research collections. Without these collections, we might not have recognized just how rich a state we had. The importance of the collections for understanding species in space and time is only just now being appreciated, mostly due to the development of databases that improve the ease of use of large amounts of information.

Illinois is thought to support over 1,800 species of aquatic macroinvertebrates within three principle phyla (Table 10.1, Fig. 10.1). There is little doubt that with additional surveys and examination of existing collections that numbers will surely rise. A recent intensive survey of the invertebrate fauna of Plummers Island, a small 4.8-hectare island in the Potomac River of Maryland, found at least 230 aquatic species (9). Putting those data into perspective, Plummers Island represents a land mass 0.00003% the size of Illinois, yet it contains a level of aquatic invertebrate diversity 12% of that found in Illinois.

The Phylum Annelida is composed of the Class Oligochaeta, or aquatic "earth worms" and the Class Hirudinea, or leeches. These two classes contribute 125 species. Nearly half of the known North American oligochaete fauna is contained within Illinois, which is an astonishing figure. Not enough is known about the past distribution of these species to ascertain any changes in the fauna through time.

Insects contribute 79% of the estimated species richness of aquatic macroinvertebrates found in Illinois. They are found in all types of aquatic habitats ranging from wet soils, to seeps, streams of all sizes, wetlands, and the largest of lakes. The best known of these are the Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) (a.k.a, EPT taxa). Our knowledge of the diversity of these insects is a result of the nearly half million EPT specimens that have been deposited in the INHS Insect Collection by well-known researchers such as T.H. Frison (10, 11), H.H. Ross (12), and B.D. Burks (13). These historical specimens allow us to directly compare historical samples with those collected today. EPTs are environmentally sensitive insects, with several endemic species now extinct and statewide extirpations of other species having been confirmed within two of the three orders. Dragonflies and damselflies have also been well studied (14) and it has been estimated that a large proportion of those fauna is at risk of extirpation from habitat alteration. The distribution, abundance, diversity, and conservation status of Coleoptera (beetles) and Diptera (true flies) is relatively poorly known for Illinois, but they are the two most species-rich orders of aquatic insects. Despite all the past research, INHS biologists are still describing new species of macroinvertebrates from Illinois and other areas and are continuing to learn more about their life histories.

The Crustacea contribute a much smaller number of species than do the insects, but have a relatively high percentage of imperiled species. One crayfish has been extirpated from Illinois (15). The isopods (sowbugs) and amphipods (scuds) that are imperiled are usually associated with cave habitats.

Freshwater mollusks in Illinois include snails (Class Gastropoda), mussels and clams (Class Bivalvia), and number about 184 species (Table 10.1). The conservation status of mussels in Illinois is well known, with five extinctions, 14 extirpations, and over 40% of the extant fauna being threatened or endangered (Table 10.1, [16]). Losses have undoubtedly occurred among the snails as well, but work has just begun to document the extent of their losses.

CURRENT STREAM QUALITY AND AQUATIC INSECTS

Until recently, comparative data to determinie statewide habitat and water quality conditions of streams were mostly inadequate (17). The Critical Trends Assessment Program (CTAP) was created 1994 to build data sets that could provide information about habitat conditions on a statewide basis. The stream sampling component of the CTAP program included 150 randomly selected sites, and the data derived from these samples are important for determining if our streams are capable of supporting aquatic macroinvertebrate diversity across the state. Three metrics were used to determine stream condition; these included EPT richness, a Habitat Quality Index (HQI), and the Hilsenhoff Biotic Index (HBI). The HQI measures 12 habitat features that have been been related to the ability of streams to support macroinvertebrates. Key features are diversity of instream habitats such as substrate types or water depths, relative bank stability, width and structure of streambank vegetative zones, and relative sinuosity of the stream channel. The HBI is an abundance-weighted average

Table 10.1. Major macroinvertebrate taxa inhabiting Illinois streams and their current richness and conservation status. *= # of species uncertain. S1=Critically Imperiled, S2=Imperiled, X=extirpated and or extinct, SE=state endangered, ST=state threatened, FE=federally endangered, and I=introduced.

Aquatic Taxa	Species	Status / Notes	Sources
		ANNELIDA	
Oligochaetes ("earth worms")	93	3 I, otherwise unknown	(45)
Hirundinea (leeches)	32	Unknown	(45)
		MOLLUSCA	
Gastropoda (snails)	76	4 I. Status largely unknown	(46), (16)
Bivalvia (mussels, clams)	108	16 SE, 8 ST, 19 X, 6 FE : 2 I	(46), (16)
		ARTHROPODA	
		Crustacea	
Amphipoda (scuds)	24	4 SE, 1 FE, 1 I	(16), (47)
Anostraca (fairy shrimp)	4	Unknown	(24)
Decapoda (shrimp & crayfish)	25	4 SE, 1 X, 1 I	(16), (47)
Isopoda (sowbugs)	17	2 SE	(16), (47)
Micro-crustacea (Cladocera, Copepoda, Ostracoda, Conchostraca, Branchiura)	132	Unknown	(24)
		Insecta	
Ephemeroptera (mayflies)	107	1 SX, possibly more	(13), (48), (49)
Odonata (dragonflies)	92	19 S1, 13 S2, 1 SE, 1 ST, 1 FE	(14), (16)
Odonata (damselflies)	43	3 S1, 6 S2, 1 SH	(14), (16)
Plecoptera (stoneflies)	77	22 X, 19 S1, 15 S2	(7)
Hemiptera (true bugs)	120*	Unknown	P. Tinerella (unpub. data)
Diptera (true flies)	400*	Unknown	D. Webb (unpub. data)
Trichoptera (caddisflies)	183	Unknown	(12), (50)
Coleoptera (beetles)	350*	Unknown	P. Tinerella (unpub. data)
Total	**1883**		

Figure 10.1. Some common macroinvertebrates found in Illinois streams and lakes. Clockwise from upper left: horse fly larva (Diptera), snail (Gastropoda), mussel (Bivalvia), scud (Amphipoda), burrowing mayfly larva (Ephemeroptera), dragonfly larva (Odonata), caddisfly larva (Trichoptera), and creeping water bug (Hemiptera). Photos by E. DeWalt.

of the pollution tolerance of the EPT community found in the stream at the time of sampling. An overall quality index was then developed as a weighted average of the three metrics (18).

Analyses of the CTAP data based on multiple metrics involving stream characteristics and EPT taxa richness demonstrated that the majority of streams in Illinois were of fair to poor condition (Fig. 10.2). Only 3% of streams were classified as excellent, while nearly half were found to be in poor condition. Forty percent of all streams

Figure 10.2. Distribution of quality ratings for 150 randomly samples stream reaches from CTAP data.

sampled were channelized (Fig. 10.3A), no longer having a meandering course or natural riparian (bankside) vegetation (Fig. 10.3B). The worst of this degradation took place in the northern two-thirds of the state, where networks of tile drains (see Chapters 5 and 14) are combined with channelization. These influences change the hydrology and hydraulics of streams and expose streambeds to direct sunshine and warmer water temperatures (19).

Channelization has a dramatic effect upon macroinvertebrates species richness in streams. Here, EPT taxa were taken as a surrogate for the entire assemblage based on their successful usage in other parts of North America. On average, channelized streams had 40% fewer species than did meandering streams. This trend held through most stream sizes (Fig.10.4).

The INHS Insect Collection documents that many species of environmentally sensitive EPT taxa were found in several areas of the state as late as the 1940s, including the now agricultural northern two-thirds of the state. However, CTAP samples have turned up only five streams (mostly in the Shawnee Hills of the southern tip of the state) where a truly sensitive assemblage of species still occurs. In agricultural areas, streams with better than average habitat quality and relatively high EPT species richness supported no species of a truly sensitive nature that were known from the historical record for the region. These results indicate that a large portion of the state's stream fauna has been homogenized, being represented by a pool of species capable of living in impaired waters.

DRAMATIC CHANGES NOTED IN STONEFLY ASSEMBLAGES

The poor condition of Illinois streams exemplified by the CTAP data is confirmed by another study, one that compared historical with contemporary assemblages of stoneflies in Illinois. Nearly 5,000 records, representing some 20,000 specimens, demonstrated that stoneflies are greatly imperiled in Illinois (7). Extirpations (20 species) and extinctions (2 endemic species) totaled 28.6% of 77 species, with the greatest losses taking place in glaciated natural divisions (e.g., Grand Prairie) and large river habitats (e.g., Coastal Plain) of Illinois (Fig. 10.5). The greatest losses were in large, long-lived, predatory species (Fig. 10.6) and took place around the late 1940s to 1950s (20). A nearly equivalent percentage of extant species are in imminent peril due to dwindling habitat and poor water quality conditions. Most streams across the state have an excess of nutrients from row crop and livestock runoff and/or domestic sewage effluents. These nutrients cause thick growths of algae that may influence invertebrates in myriad ways, including depression of oxygen concentrations at night through their own respiration, by making substrates unsuitable as resting sites, and through changes in the kind and abundance of preferred food sources, supplanting them with poor or noxious ones. Still, a large number of streams in Illinois (40% of CTAP sites) are channelized and many lack native streambank vegetation. This makes for less diverse stream depths, current velocities, food sources, and adult resting and mating habitat streamside. In the southern third of the state, water runoff from farm fields in the plateaus between forested ravines leads to unstable stream bottoms, sheer and often stranded bank habitat, and ever widening channels due to bank failure.

What does the future hold for these species? Currently, there is no evidence that any species have returned since being lost and there might not be any natural recolonization.

Figure 10.3. A. Channelized stream with poor habitat. B. Meandering stream with diverse habitat. Photos

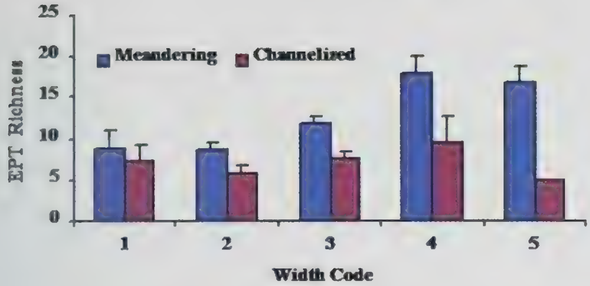

Figure 10.4. EPT species richness by relative stream size for meandering and channelized stream reaches. Increasing code signifies increasing width. Numbers in bars indicate sample size.

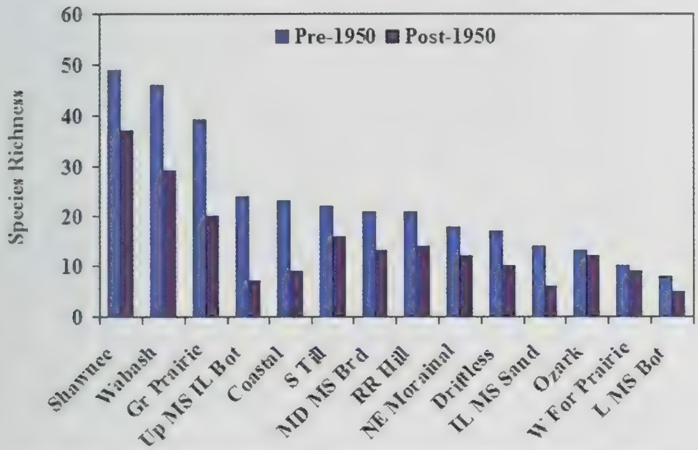

Figure 10.5. Pre- and post-1950 stonefly species richness in Illinois natural divisions.

Figure 10.6. Perlidae stonefly nymphs extirpated or experiencing range loss in Illinois. Clockwise from top left: *Acroneuria abnormis*, *A. frisoni*, *A. internata*, and *Agnetina capitata*. Photos by E. DeWalt.

The closest extant populations for species in the genus *Acroneuria* (Fig. 10.6) range from 100–300 km away from historic Illinois locations; the sources for most being from neighboring states (DeWalt, unpublished data). These species would have to travel across inhospitable habitat and survive water quality that is relatively poor in order to recolonize the state. However, once here, there are streams where they could survive. The Middle Fork Vermilion River (Illinois' only designated National Wild and Scenic River) has better water and habitat quality than many Illinois rivers. Reestablishment of part of the state's historical biological heritage could take place here, but would require physically moving species from areas where they still exist. Efforts are underway to restore these assemblages and future monitoring will be needed to determine the success of these efforts.

FRESHWATER CRUSTACEANS

ECOLOGY, DIVERSITY AND HISTORY

The nearly 40,000 extant species of crustaceans represent one of the most diverse groups of animals found on Earth, trailing only Mollusks and insects (21) in terms of global species diversity. Crustaceans are closely related to insects in that they have a hard chitinous exoskeleton and multiple jointed appendages, but differ in having two pairs of antennae instead of one. In many ecosystems, crustaceans comprise a significant portion of total biomass (21) and perform important ecological functions such as organic matter breakdown and nutrient transfer (22). Most crustacean species are aquatic and several, such as crayfishes, lobsters, crabs, and shrimps, are commercially harvested as part of a multibillion-dollar fishery, providing a valuable source of protein.

Crustaceans occur in every aquatic habitat in Illinois, including intermittent and permanent seeps, streams, large rivers, Lake Michigan, and ephemeral woodland ponds. Some burrowing species of crayfishes even border on being classified as terrestrial. These crayfishes build extensive systems of subterranean burrows that can be found several hundred meters from any body of water. Only the sowbugs (Isopoda) contain members that are truly terrestrial. Also called pillbugs, these terrestrial isopods are frequently encountered under fallen timber or around house foundations where moisture is present.

While crustaceans may be one of the most diverse and economically important groups of organisms on the planet, basic knowledge of their biology is lacking for most members, especially freshwater species. It has only been within the last 50 years that rudimentary distribution patterns for many freshwater crustaceans have become known. This lack of knowledge hinders our ability to examine large-scale changes in crustacean populations.

Our knowledge of the Illinois crustacean fauna began with the Illinois Natural History Survey's first leader, Stephan A. Forbes, who published a list of all known crustaceans from the state (23). That list included eight crayfish, two shrimp, seven amphipods and isopods, and three fairy shrimp. Ever insightful, Forbes stated that the importance of crustaceans should not be overlooked, as the "progressive settlement of the country" would lead to increased pressure on our fisheries and that we should strive to gain "an acquaintance with the natural history of our crustaceans, which are as essential to fishes as insects are to birds" (23). While much significant research took place elsewhere, Forbes' comments went unheeded for the majority of the Illinois crustacean fauna. Crayfishes and shrimps (Decapoda) are the largest and most frequently encountered crustaceans in Illinois and, as such, have received the most attention. Aspects of the ecology and distribution of decapods occurring in Illinois were summarized by another INHS researcher, L.M. Page in 1985 (15).

The diversity and status of other aquatic macrocrustaceans, including scuds (Amphipoda), pill bugs (Isopoda), and fairy shrimps (Anostraca), are known with a limited degree of certainty in Illinois (Table 1). However, no such certainty exists for microcrustaceans. Microcrustaceans are generally less than 1 mm in size and are collectively referred to as zooplankton. In Illinois, they include water fleas (Cladocera), seed shrimp (Ostracoda), clam shrimp (Conchostraca), and copepods (Copepoda), and are estimated to include 132 species (24).

KNOWN CHANGES AND THREATS

The lack of long-term datasets hinders our ability to measure large-scale changes in most crustacean populations. Most crustacean groups such as clam shrimps, fairy shrimps, amphipods, and isopods have only received passing mention of their occurrence in certain Illinois habitats, while some microcrustaceans were extensively studied, albeit in limited geographic and temporal scales. An example of the latter is the work C.A. Kofoid who published over 1,000 pages of information on the distribution, seasonal abundance, and life history of the phyto- and zooplankton of the early twentieth century Illinois River (25, 26). This presents a yet untapped opportunity to determine changes in the planktonic food base of this large and important aquatic system.

Crayfish and shrimp represent perhaps the only crustacean group for which we can assess long-term changes. Through the work of Forbes (23), Page (15), and other recent researchers, we know that Illinois is home to 22 native species of crayfishes and 2 species of shrimp. Given the diversity of habitats, the unglaciated Shawnee Hills and Coastal Plain regions of southern Illinois harbor the greatest number of Decapods with 16 species. The long history of work in Illinois has documented that at least two species have experienced dramatic changes and these changes demonstrate that the same anthropogenic activities discussed in other chapters of this book (see Chapters 4, 5, and 9) have affected crustaceans. The Ohio Shrimp, *Macrobrachium ohione*, (Fig. 10.7) is a large (>100 mm) freshwater shrimp that once occurred commonly in the lower Ohio River and the Mississippi River downstream of St. Louis (15). It is one of five species of freshwater shrimps in the United States and was once so common that a fishery for the species was supported in southern Illinois and other regions of the United States bordering the Mississippi River. Forbes (23) stated that the species was frequently eaten in Cairo, Illinois, while others reported its harvest and sale by fisherman for bait and human consumption from Chester, Illinois, down to Louisiana (27). Interestingly, Gunter (27) stated that "If undue pollution of the river does not arise, the present fishery for the freshwater shrimp will probably be maintained indefinitely, for the present method of trapping captures only the larger animals and leaves the smaller ones to carry on." This prognostication did not bear out as commercial fisherman along the Mississippi River in Kentucky, Illinois, and Missouri began to notice the absence of river shrimp in the 1940s (28) and the harvest of the species all but disappeared shortly thereafter. Page (15) did not find the species in Illinois during his statewide decapod survey and it was not until 1991 that it was again collected in the state. Two individuals were captured in 1991 at a site that had been sampled for 14 straight years without encountering the Ohio Shrimp (28). Since that time, low numbers of Ohio Shrimp have been collected sporadically from the Ohio and Mississippi rivers in southern Illinois (29).

The Ohio Shrimp occurs in flowing side channels and along main channel margins of large rivers. Within its native range, the habitat of the Ohio Shrimp has been drastically altered in Illinois and across the upper Midwest. Large midwestern rivers have served as conduits for the transportation of agricultural and other natural resource products for over 150 years. This transportation industry led to the development and growth of human populations along rivers, which subsequently led to the construction of extensive flood control structures.

To facilitate commercial barge traffic and minimize seasonal flooding events, both the Mississippi and Ohio rivers have become highly regulated with locks, dams, and levees. Locks and dams (Fig. 10.8) turn free-flowing rivers into a series of slow flowing pools. Levees confined floodwaters that once nourished extensive floodplain forests and backwater lakes that are critical for the life histories of

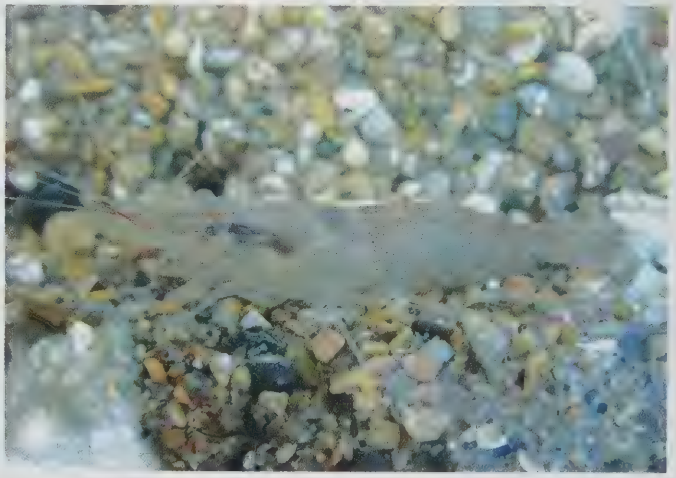

Figure 10.7. The Ohio Shrimp, *Machrobranchium ohione*, a species once found commonly in big rivers bordering Illinois. Photo by Missouri Department of Conservation.

many aquatic species. Four locks occur on the Ohio River along the southern border of Illinois, while no locks occur in the Mississippi River between the mouths of the Missouri and the Ohio rivers. Here, navigation depth is maintained by dredging and by wing dikes (29).

Lock, dams, and levees drastically alter flow regimes by curtailing spring flood pulses and increasing flow rates in main channels. Wing dikes also create areas of reduced flow and increased visibility immediately downstream. The above alterations have most likely affected Ohio Shrimp populations in Illinois by limiting access to backwater areas of rivers by females during reproduction and by reducing or eliminating flows along channel margins, thus making the water less turbid, contributing to predation by fishes (29). While populations of Ohio Shrimp remain stable in the Mississippi River drainage of Mississippi and Louisiana where the river gradient is lower and locks and dams are not present, the likelihood of the species returning to historical abundance in the highly altered upper Mississippi and lower Ohio rivers remains low.

Figure 10.8. Locks and dams such as this one on the Illinois River near Starved Rock State Park have dramatically altered once free-flowing rivers. Photo by M. Jeffords.

Perhaps the greatest transformation of crustacean populations in Illinois has occurred due to the introduction of the Rusty Crayfish (*Orconectes rusticus*) and its effects upon native crayfish species. The influx of exotic species into Illinois has been continual since European settlers first set foot in the state (see Chapter 11). Many exotic species do not become established or have minimal impacts on our natural resources. However, some can have significant detrimental effects on native flora and fauna.

The Rusty Crayfish is native to the Ohio River drainage in southwestern Ohio, southeastern Indiana, central Kentucky, and in the Lake Erie drainage in southeastern Michigan and northwest Ohio (30) and was first discovered in Illinois in 1973 (15). Through its use as fishing bait, the Rusty Crayfish was introduced into approximately a dozen sites in northern Illinois over the next 12 years. Since then the species has spread rapidly across northern Illinois (Fig. 10.9) and in the process has eliminated populations of the native Northern Clearwater Crayfish (*Orconectes propinquus*) and reduced populations of the native Virile Crayfish (*Orconectes virilis*). It is this displacement ability that sets the Rusty Crayfish apart from other exotic aquatic species.

EXOTIC SPECIES

Twenty-two species of exotic fishes are now established in Illinois waters (see Chapter 9) and while impacts on native species and ecosystems have been documented in habitats containing those exotics, there is yet to be a single case of an exotic completely eliminating a native fish population. Throughout the Des Plaines, Fox, Rock, and Vermilion River drainages of northern Illinois, populations of the Northern Clearwater Crayfish are no longer found at sites now occupied by the Rusty Crayfish (Fig. 10.9). This displacement is swift, as field efforts and specimen data housed in the INHS Crustacean Collection document. Northern Clearwater Crayfish are usually eliminated within five years of Rusty Crayfish introduction in lakes (31). The spread of Rusty Crayfish within streams also is rapid, possibly up to 1 km annually. Populations of the Virile Crayfish do continue to exist at sites invaded by Rusty Crayfish, albeit in small numbers, and displaced from their normal riffle habitats that are now occupied by the Rusty Crayfish. A number of displacement mechanisms have been proposed, including hybridization between the two species that swamps out of the *O. propinquus* genotype and through competition for food and shelter exacerbated by the invader's aggressiveness (32).

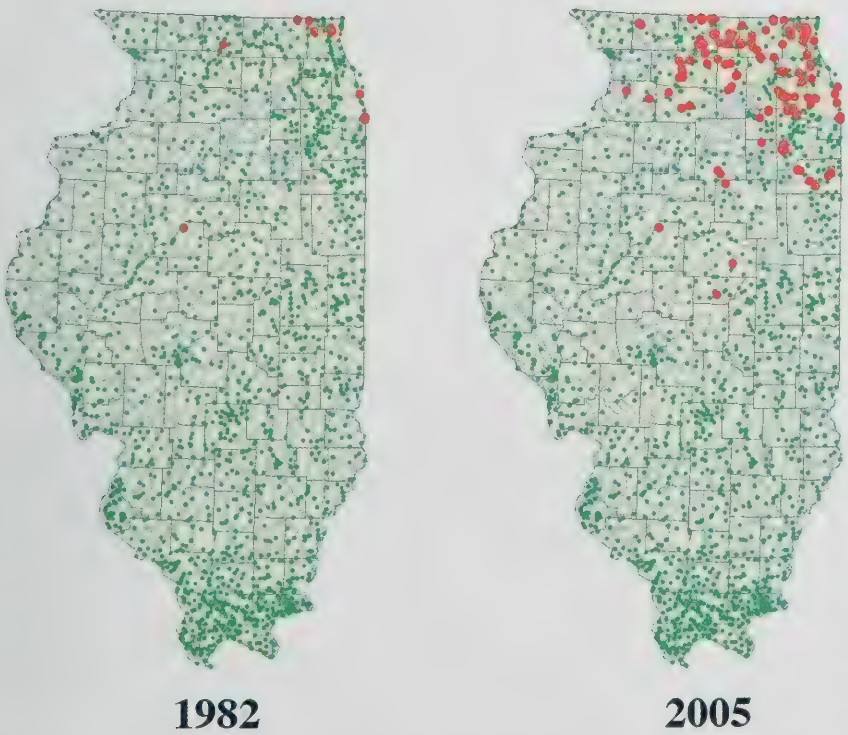

Figure 10.9. *Orconectes rusticus* range map, 1982 and 2005. Red dots indicate collection sites. Green dots indicate sites at which crustaceans were collected but *O. rusticus* was not present.

The impacts of exotic crayfish are not limited to Illinois or to other native crayfishes. The Rusty Crayfish also was introduced into Wisconsin in the mid-1960s and has now spread across the entire state and accounts for 36% of all crayfish records (33). It has eliminated numerous populations of native crayfishes and has had dramatic impacts on the ecology of lakes in that state (32), most notable being the reduction of rooted aquatic vegetation that plays an important role in the growth of juvenile sport fishes by offering them refuge from predation. Several other crayfish species have been introduced across the United States and Canada and the list of organisms negatively affected by those introductions range from algae to amphibians (32).

Those species that have experienced changes over the past 150 years have suffered the effects of habitat alteration and the introduction of exotic species, the same causes of decline implicated for many other taxonomic groups discussed throughout this book. While impacts like the introduction of exotic species may be irreversible, some progress is being made. For example, Illinois law bans the possession of live Rusty Crayfish and this action may slow the spread of the species. Other positive efforts include an increased awareness of crustaceans by private conservation groups (i.e. The Nature Conservancy) through sampling efforts in the Illinois River basin and the listing of four crayfish, two isopod, and four amphipod species under the Illinois Endangered Species Act (Table 10.1). Given the importance of crustaceans in aquatic ecosystems, we cannot afford to continue to neglect this diverse and interesting group of aquatic organisms.

FRESHWATER MOLLUSKS

ECOLOGY, DIVERSITY, AND HISTORICAL USES OF MUSSELS

The Phylum Mollusca (mussels, clams, oysters, snails, slugs, octopi, and squid) is diverse and has been estimated to contain more than 100,000 described species worldwide. Freshwater mussels occur on every continent except Antarctica but are most diverse in eastern North America, where they number nearly 300 species. Fingernail clams number about 40 species in North America north of Mexico, while approximately 650 species of freshwater snails have been reported from this region. Illinois freshwater mollusks include mussels (also called naiads or unionids), fingernail clams, and snails. Mussels and fingernail clams are bivalves, whereas snails have a single coiled or flattened shell. Illinois historically supported 80 species of mussels, 26 species of fingernail clams, and 72 species of native freshwater snails.

Freshwater mollusks are a vital component of stream ecosystems. Not only does their sensitivity to water quality and physical habitat allow them to be used as biological indicators of stream integrity, but they also occupy a central position in food webs and help stabilize streambeds (34, 35). Mussels are an important food source for a many animals including muskrats, minks, otters, fishes and some birds. Large piles of freshly cleaned mussels, called middens, can be found along the banks of a river or lake where muskrats are actively foraging.

Mussels spend their entire life buried in mud, sand, or gravel in permanent bodies of water. The vast majority of freshwater mussels is found in streams, although a few species can occasionally occur in ponds or lakes. Mussels occupy a wide variety of habitats (pools, runs, and riffles) and substrate types (mixed mud, sand, and gravel), but are usually absent or rare in areas of silt or shifting sand.

Mussels have a life cycle that is unique among the bivalves (Fig. 10.10), in that they must pass through a parasitic phase to complete their development. In most species, the sexes are separate, but some are hermaphroditic. Males release sperm into the water, which is then taken in by the female via the incurrent siphon. The eggs are fertilized internally and develop into an intermediate larval stage termed a glochidium. Glochidia are stored in the female's gills that function as a brood chamber. In the spring or summer, glochidia are expelled into the water and must come into contact with an appropriate host (most often a fish, but the mudpuppy, *Necturus maculosus* is also known as a host), to which they attach and form a cyst. The glochidia are either internal parasites on the gills or external parasites on the fins. Some species are host-specific, while others can use a wide variety of fishes as hosts. While encysted, the larva changes form and except for size, resembles an adult mussel. After metamorphosis, the young mussel breaks from the cyst and drops to the bottom to begin an independent life if favorable conditions are present. The period of attachment varies from about 1 to 25 weeks depending on the host, location of attachment, and temperature. Typically, no harm is done to the host and over time the host can become resistant to re-infestations of glochidia.

Mussels are filter and pedal feeders that consume organic matter (bacteria, detritus, or plankton). Mussels are among the longest-lived invertebrates, with many species living 10–20 years and some reported to live over 100 years. Thin-shelled species grow much faster than thick-shelled species. In some individuals, dark lines are apparent on the surface of the shell, which, like trees rings, are believed to represent annual winter rest periods and are often used to estimate the age of a mussel.

Native Americans, particularly the mound-building tribes of the Midwest, collected and used mussels long before Europeans set foot in North America. Mussels were eaten and used for making utensils, tools, jewelry, and tempering pottery (36, 37, 38). In the late 1800s and early 1900s, vast numbers of mussels were harvested and used in the manufacture of pearl buttons for clothing (Figs. 10.11 and 10.12). Button making was a multimillion-dollar industry early in the twentieth century and hundreds of factories were operating in towns like Muscatine and Keokuk, Iowa, and Peoria and Beardstown, Illinois (39). The pearl-button industry collapsed with the invention and widespread use of plastics in the 1940s and 1950s. By the 1950s, the Japanese devised a method to culture pearls for jewelry out of mussel shells. The shells are cut and finished into beads and inserted into oysters that serve as nuclei for cultured pearls.

Conservation and Changes in the Illinois Fauna— Unfortunately, freshwater mollusks are one of the most imperiled groups of animals in North America. As with the

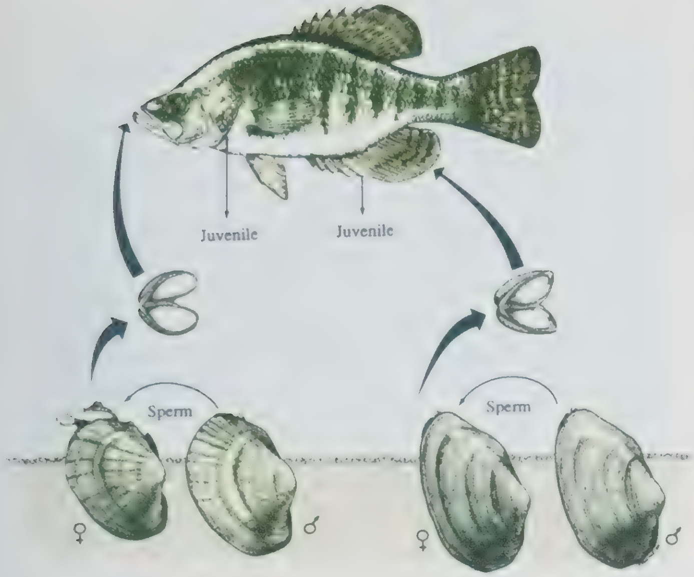

Figure 10.10. The reproductive cycle of a freshwater mussel. (see text for details) (51).

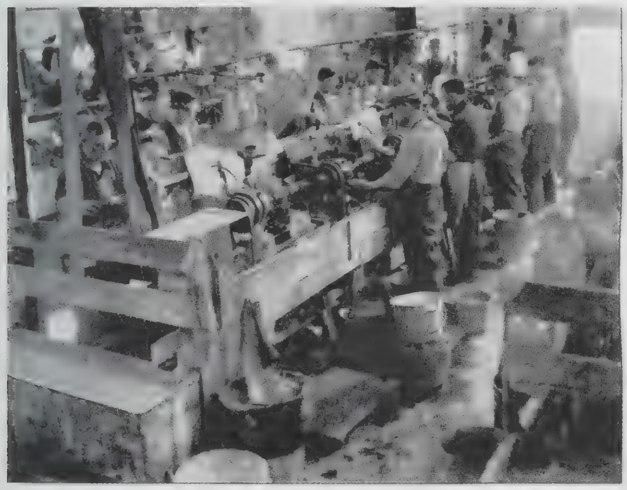

Figure 10.11. Workers use cutting machines to drill blanks for pearl buttons, circa 1910. Photo from U.S. Bureau of Fisheries.

Figure 10.12. Mussel shell barge headed to a buying station, Black River Arkansas, circa 1920. Photo from U.S. Bureau of Fisheries.

invertebrate groups mentioned in this chapter, the primary factors responsible for the decline of freshwater mollusks include impoundments, dredging, channelization, siltation from deforestation and agriculture, contamination from human and livestock wastes, pesticides, gravel mining, over-harvesting, and impacts from exotic species like the Zebra Mussel (*Dreissena polymorpha*) (Fig. 10.13). At least 70% of the nearly 300 freshwater mussel species and over 40% of the estimated 650 freshwater snail species in North America are extinct, listed as federally endangered or threatened, or are in need of protection (34, 40). A similar decline in species presence is evident in Illinois (Table 10.1). Of the 80 freshwater mussel species native to Illinois, 19 are extirpated (of which 5 are extinct), 24 are state-protected (of which 6 are listed at the federal level), and 15 have relatively unstable populations (8, 41). However, little is known about the status of the state's 72 freshwater snail species or of the 26 fingernail clam species, although anecdotal evidence suggests that they may have met a similar fate. Work is currently underway to improve our knowledge of these two important groups.

Species richness in Illinois has historically been greatest in the Wabash-Ohio River drainage (8, 41). This drainage supported 79 species, of which about 25 were found only in this basin in Illinois. However, only 61 species (76%) have been recorded alive in the Wabash-Ohio drainage since 1970, and some of these species are isolated, nonreproducing populations. The Illinois-Mississippi River drainage, exclusive of the Wabash-Ohio drainage, historically supported 59 species, of which only the Higgins' Eye (*Lampsilis higginsii*) is known solely from this part of the state (8, 41). Here 47 (80%) species have been found alive since 1970. Most Illinois drainages have experienced at least a 25% loss in species richness (8, 41). Declines in species richness vary from 18% (8 of 45 species lost) in the Vermilion River basin (Wabash River drainage) to 71% (27 of 38 species lost) in the Des Plaines River basin (Illinois River drainage).

One example of a regional change in a mussel fauna was documented for the Illinois River mainstem. In 1966, William C. Starrett of the INHS conducted a comprehensive survey of the Illinois River using a variety of collecting techniques. A total of 4,249 mussels were collected alive from 429 sites along the entire Illinois River from Dresden to Grafton (42). Starrett collected less than half of the species (23 of 47: 49%) historically known from the Illinois River, and 5 of the 23 species he did find were represented by single specimens. He concluded that a combination of industrial, agricultural, and domestic pollution caused the decline, and stressed the need for a strong soil conservation plan for the basin. Thirty years after Starrett's study, INHS researchers documented that post-1990, 27 species have been recorded from

Figure 10.13. A native freshwater mussel (*Potamilus alatus*) with exotic Zebra Mussels (*Dreissena polymorpha*) attached to its shell. Photo by K. Cummings.

the Illinois River mainstem, including 12 species in the upper portions of the mainstem where none had been found in the 1960s (43). This recolonization was likely the result of glochidia being carried upstream by fish from other sections of the basin.

A second example of a regional change in mussel populations is in the Little Wabash River. The mainstem of the river historically supported 41 species. Thirteen mainstem sites were sampled in each of 1956, 1988, and 2007. In 1956, 1,205 individuals of 29 species were collected alive. The Threeridge (*Amblema plicata)* (29.0% of total), Mapleleaf (*Quadrula quadrula*) (17.5%), and Pimpleback (*Quadrula pustulosa*) (14.5%) were the three most abundant species collected, accounting for 61.0% of the total catch. In 1988, 1,124 individuals of 24 species were collected alive. The Washboard (*Megalonaias nervosa*) (22.4%), *A. plicata* (16.7%), and *Q. quadrula* (15.9%) were the three most common species found and made up 55.0% of the total catch. In 2007, 2,054 individuals of 19 species were found alive, and *Q. quadrula* (33.0%), *M. nervosa* (18.0%), and the Pistolgrip (*Tritogonia verrucosa*) (15.0%) were the three most abundant species collected and accounted for 66.0% of the total. Species richness declined throughout the study and the dominant species also changed.

Species in the genus *Epioblasma* (Fig. 10.1) comprise one group of mussels that has experienced a drastic decline in species richness and distribution in the state and throughout its range. Historically found in the Wabash-Ohio River drainage (except for the Snuffbox *Epioblasma triquetra*, which was formerly also found in the Mississippi Basin), eight of the nine members known from Illinois are either globally extinct or extirpated from the state. The lone survivor, *E. triquetra*, is found only in a small (< 40 km) reach of the Embarras River in southeastern Illinois.

Impoundments are one of the major sources of anthropogenic disturbances on streams. Dam effects include converting free-flowing stream habitats to lake habitats, altering water quality, increasing siltation upstream of and scouring substrates downstream from the dam, and altering fish assemblages and/or blocking movement of host fishes. The resultant effects of dams can alter the mussel fauna, including restricting distributions and isolating populations, reducing native fauna, and increasing non-native faunas.

Because commercial harvest was unregulated for decades, this activity had a negative effect on mussel populations (42). In Illinois, commercial musseling was legal in the Illinois, Wabash, Ohio, and Mississippi rivers, but it recently has been restricted to the Ohio River and parts of the Illinois River (8). Some states have passed moratoria banning commercial harvesting, while others have established refuges in order to protect mussels. These management strategies have had mixed results and data are being analyzed to evaluate their effectiveness (44). In addition, poaching occurs in many streams not open to harvest (8).

Conservation efforts are critical to the preservation and restoration of all aquatic assemblages. Propagation facilities currently are being used to help re-establish some of the most imperiled species. In the past 15 years many state and federal fish hatcheries have begun rearing freshwater mollusks. One such example is the Higgins' Eye reintroduction project occurring in the upper Mississippi River basin of northern Illinois, Iowa, Minnesota, and Wisconsin. This multi-state, multi-agency project has begun to reintroduce and bolster Higgins' Eye populations. Although never common, the Higgins' Eye has experienced a reduction in its range and density as the result of impoundments, dredging, increased sedimentation, and introduction of the exotic Zebra Mussel. The U.S. Fish and Wildlife Service's Genoa National Fish Hatchery in Wisconsin propagates the Higgins' Eye each spring. Divers collect gravid females and then pass them to biologists, who remove the glochidia and infest host fish such as Largemouth Bass, *Micropterus salmoides*, and Walleye, *Sander vitreum*, with glochidia. After infestation, the fish are released directly into the river or are held in underwater cages over suitable habitat until juvenile Higgin's Eye are released. This program has been highly successful and is being expanded to include additional species.

All is not lost for freshwater mollusks. Many preservation and restoration projects, including creating and restorting wetlands, protecting high-quality streams, and removing dams, are currently being implemented to help conserve aquatic resources (see Chapter 16). However, more resources are needed to study and protect essential habitat for these unique and important animals. As funds for conservation programs increase, the aquatic fauna of Illinois will improve, benefiting wildlife and humans alike.

CONCLUSIONS

Illinois has a diverse aquatic macroinvertebrate fauna. The state's combination of biomes, rivers, and climatic zones supports a species-rich and tremendously productive macroinvertebrate fauna. We are grateful that early INHS researchers saw the need to document this great bounty through the deposition of millions of specimens in various invertebrate collections. These collections allow current researchers to tell a story of the dramatic shifts in aquatic macroinvertebrates that are the result of the nearly complete conversion of Illinois' prairies and woodlands to the vast agricultural economy and large cities that now dominate the landscape.

Many macroinvertebrate species have been lost from Illinois. The best documented of these losses are of mussels (8) and stoneflies (7). Other changes are more subtle, such as the loss of native crayfish populations as the exotic Rusty Crayfish continues its march across the state. It is true that with time INHS scientists will document other aquatic macroinvertebrates that are imperiled or have been lost, and in doing so will demonstrate the tremendous value of our natural history collections. Losses among the stoneflies are probably indicative of what has taken place for mayflies and for caddisflies. Losses of mussels will likely portend a similar fate for aquatic snails once the data have been gathered and analyzed.

The losses experienced by macroinvertebrates are not great stories to tell, but in doing so, we allow for the extant species to be given state protection by listing them as threatened or endangered. This knowledge will allow government and other private conservation agencies to set conservation priorities for species and the habitats that support them. Having these basic distributional data for historic and extant populations also allows researchers to ask detailed research questions and test hypotheses. As always, scientists look at new discoveries and ask additional questions of the data. The authors see much opportunity in the current data—opportunity for reclaiming some of Illinois' biological heritage.

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CHAPTER 11

150 Years of Fishery Science: Changes, Progress, and the Role of the Illinois Natural History Survey

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Illinois Natural History Survey

OBJECTIVES

The field of fisheries science has changed dramatically during the last century and a half. We describe some of the major themes that have developed in fisheries ecology and management and consider the ways in which the Illinois Natural History Survey has influenced these research areas, beginning with the early work of Stephen Forbes and George Bennett. Understanding recruitment variation has been and continues to be one of the central questions in fisheries, and the food web approaches first identified by Forbes have guided much progress in these areas. Through time, the focus on stocking hatchery-raised fish has shifted from maximizing production to consideration of growth and survival, implications for the genetic integrity of native populations, as well as implications for the rest of the aquatic ecosystem. Some introduced species, such as Common Carp, we now consider to be ecological pests and are still learning about their wide ranging negative impacts. A number of management problems such as stunting in fish populations initially focused on the role of angler harvest. We now understand the role of population social structure in influencing size structure, which leads to alternate management approaches. Similarly, understanding the effects of angling on nesting success and the effects of temperature on fishes has changed management practices.

INTRODUCTION

"The animals of such a body of water are, as a whole, remarkably isolated—closely related among themselves in all their interests, but so far independent of the land about them...It forms a little world within itself – a microcosm within which all the elemental forces are at work and the play of life goes on in full, but on so small a scale as to bring it easily within the mental grasp." (1)

Fisheries ecology is the study of the interactions that determine the distribution and abundance of fishes. Factors that can interact with fish populations include physical, chemical, and biological variables in the environment. Fisheries science is ultimately concerned with the management and stewardship of all aquatic resources. In addition, fishing is culturally significant as a form of recreation and providing sustenance, with important economic impacts. The Illinois Natural History Survey (INHS) has had a long and distinguished history of conducting and producing ecological research aimed at synthesizing a balance of natural resources (including fishes) and societal uses, and much of that work has influenced fisheries science as a whole. In the early years, scientific research at the INHS was a composition of natural surveys aimed at cataloging and identifying the flora and fauna within state boundaries. Stephen Forbes (Fig. 11.1), a pioneer in ecological research, led projects to examine water quality and fish within their aquatic ecosystem (1, 2). Forbes synthesized the idea of a balance between organisms and their environment and the interactions that exist between each and studied ecological principles before the word 'ecology" was even coined. His studies ranged from examining the gut-contents and diets of 87 species of Illinois fish to whole lake studies in Yellowstone National Park where he tried to understand what attributes contributed to the diversity of ecosystems observed between lakes (1).

"The microscopic life in a cubic meter of water is at certain times far in excess of the amount recorded for any other situation in the world" (1)

Forbes established a biological field station in Havana on the Illinois River in 1894, the first of several biological stations established within the INHS. During the 1890s and early 1900s, Charles Kofoid and Forbes studied the plankton, benthos, and fish in the river. In 1903, Forbes employed another influential figure, Robert E. Richardson. Together they published the authoritative fish identification guide in North America entitled *The Fishes of Illinois*. During this span, Forbes and Richardson (Fig. 11.1) were engulfed in the ever increasing impacts

of human development. From raw sewage, to levees along rivers, to changes in flora and fauna, data were collected and predictions made about the long-term effects of increased human activity. They observed first-hand the destruction of fisheries and invertebrate populations due to human population growth. Non-native fish species such as Common Carp were widely introduced for sport and commercial fishing during this time, species that would ultimately represent a major human impact on aquatic ecosystems.

From the 1920s through the early 1940s, increased interest in sportfishing and the building of reservoirs by the Civilian Conservation Corps shifted focus to fisheries management. Primary systems used in early management experiments included newly impounded waters and older reclaimed ponds. Management themes for these systems were producing the desired fishery with minimal influence of undesirable species. George W. Bennett of INHS led this research as he examined stocking combinations and the resulting fish populations. He first examined the effectiveness of stocking ponds with a single species (Largemouth Bass) and a Largemouth Bass and Bluegill combination. He felt that these smaller systems were ideal for understanding the dynamics of fish populations and that larger systems were "practically beyond the scope of the fish manager" (3). Research was limited by the "interest or convenience" of pond owners to follow through with study ideas (4). The need for state-managed water with ability to control water and drainage was evident. On April 17, 1941, Ridge Lake (Fig. 11.2) was opened with Bennett as director and became the first and only state-owned lake dedicated to research.

Figure 11.2. Ridge Lake when first opened to fishing in 1941.

Most of the research at this time was presented as lake management reports. These reports contained extensive details of the study lake and its fish populations and included any management practices that were being undertaken. These studies were more observational than designed studies, but contributed to the knowledge on fish population dynamics and pond and lake management techniques. Bennett authored a majority of these reports with the help of his research support staff from the 1940s through 1960. His research included numerous management reports on a number of lakes throughout Illinois (5, 6, 7). Bennett also initiated a number of experiments examining cropping and overfishing populations. These experiments showed that fish in small ponds had the ability to withstand high angler pressure. In some instances growth rates increased for fish populations that were experiencing cropping or angling mortality. Bennett attributed this growth compensation to the redistribution of prey resources. Reduced competition and greater prey availability led to increased growth in the remaining fish. The thread of this early work continues to this day by researchers at the Illinois Natural History Survey and other institutions across the country. The effects of catch and release angling and tournaments on fish populations are being evaluated currently at Ridge Lake as well as other lakes throughout the state.

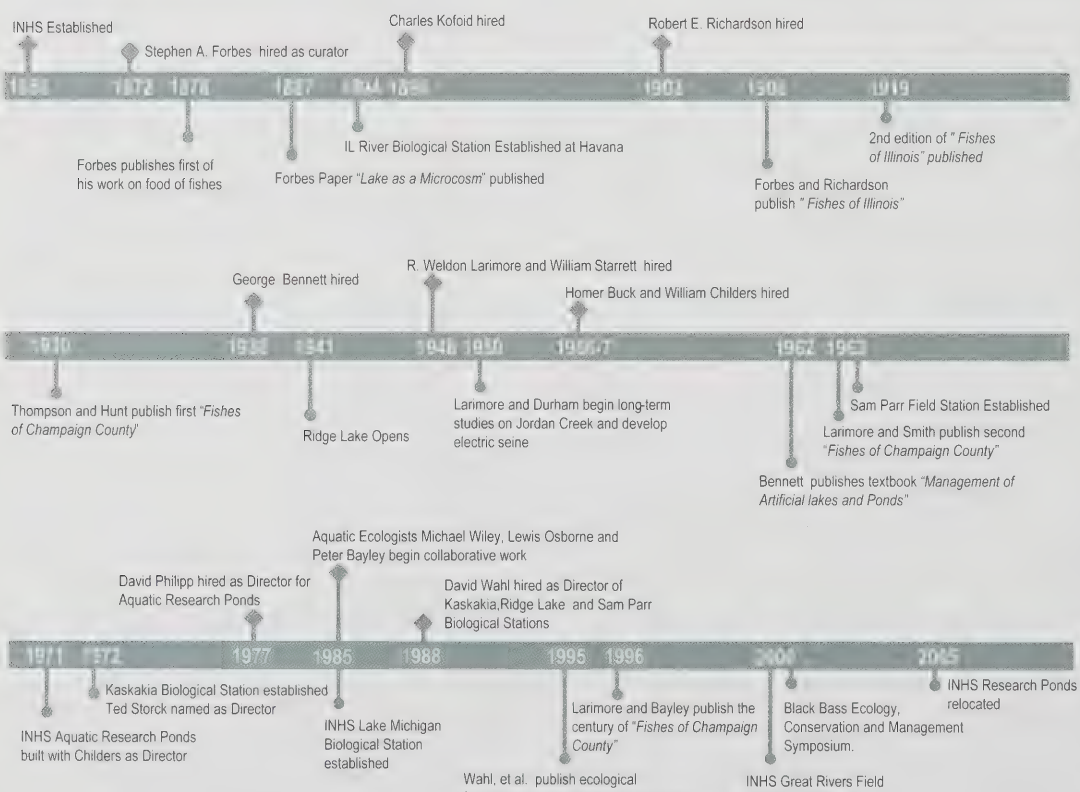

Figure 11.1. Timeline of important events related to fisheries science at the Illinois Natural History Survey.

One primary pond management concept developed during this time period was by H.S. Swingle of the Auburn University. Swingle believed that ponds or small reservoirs should be managed for a balance between species, and a good fish population would not be dominated by a single species of fish. He defined a balanced population as one with a balanced ratio of forage to piscivorous groups of fish. These populations were deemed "capable of producing satisfactory annual crops of harvestable fish" (8). Bennett's research suggested quite a different approach to fisheries management. He believed that the fish population was dynamic and argued that the size and number of fish determined the population rather than the balance of species. He disagreed with the idea that a fishery could be assessed by examining a balance between species because it did not assess adult populations when determining a "good fishery." Bennett provided further support for this criticism by attempting to utilize the minnow seining method described by Swingle to evaluate ponds and compared the assessment with a different, longer gear type (100-foot seine). Bennett found the adult fish captured with the second gear type were not predicted by the minnow seine method. In a number of reservoir experiments, Bennett had observed highly fluctuating populations and out of balance populations that yielded exceptional fisheries. He believed this research showed that fish populations should be managed more carefully with focus on available prey, carrying capacity, competition between fish for resources, and managing the fishery to achieve the desired goal. These ideas contributed to the foundation of food web dynamics that is currently the focus of much research in modern fisheries management.

Bennett (9) went on to author a comprehensive book on his management ideas titled *Management of Artificial Lakes and Ponds*. In this book, Bennett summarized management of artificial waters using his applied research. For example, he acknowledged the Bass-Bluegill stocking combination of Swingle as successful (8), but noted that it could end in Bluegill-dominated systems in some areas. He also showed evidence opposing the idea that high growth in new systems is due to organic decay. Bennett used Ridge Lake as an example where there was reoccurring high growth following each of 8 drainings that occurred over a 20-year period (Fig. 11.3). Through his research, Bennett made a major contribution to the field of fisheries, in particular, pond and reservoir management. Many of his techniques are employed today and the annual count of caught fishes (creel survey) that he initiated at Ridge Lake in 1941 is still in effect today.

Several approaches developed by Forbes and Bennett have helped guide fisheries research at the INHS and throughout the world. Long-term data collection initiated by Forbes has been emulated throughout the history of the INHS (see SIDEBAR on the Value of Long-term Fisheries Data). A number of studies have assessed the effects of anthropogenic impacts, with recent research examining, for example, the effects of fish stocking and recreational fishing. As initially conceived by Forbes and Bennett, fisheries management is no longer concerned with only a single species of sport fish, but rather understanding the effects at all trophic levels. Food web and trophic level interactions have guided a great number of ecological investigations, specifically, the examination of predator-prey relationships and factors influencing recruitment in fish populations. As the economic and cultural importance of our freshwater resources has grown, our approach to understanding aquatic ecosystems has evolved from these early years. Even so, the end goal has remained the same; stewardship of aquatic resources and the perpetuation and restoration of aquatic ecosystems to meet future challenges through research, monitoring, and adaptive management. In subsequent sections, we will explore a number of the research themes that have developed in fisheries ecology and how those themes have impacted aquatic ecosystem conservation and management. As we proceed through each of these, we think it is useful to consider the myriad of ways in which Forbes' and Bennett's ideas influenced these research studies.


Figure 11.3. Draining Ridge Lake in the 1950s.

THE LAST 50 YEARS: MAJOR FISHERIES RESEARCH THEMES

EVALUATION OF FISH STOCKING SUCCESS

Fish stockings are a major fisheries management technique employed in Illinois and throughout the world. Initial stockings in Illinois were intended to populate new waters with desired fish species combinations. With the increased construction of new impoundments during the 1950s through 1970s, stocking was commonly used to populate these new reservoirs. Fish used in stockings were often removed from a donor reservoir with what was thought to be the desired fish to stock. In 1959, the Little Grassy Fish Hatchery was opened and the state of Illinois began raising fish for stocking purposes. Since then, the state has expanded the Little Grassy Fish Hatchery (1982) and opened three additional state hatcheries, the largest being the Jake Wolf Memorial Fish Hatchery (1982), LaSalle Fish Hatchery (1994), and the Spring Grove Fisheries Resource Center. These hatcheries are now capable of producing 50 million fish of 18 species.

Early research by Bennett regarding stockings focused on smaller systems such as ponds and small

impoundments. Common management techniques in ponds with undesirable fish combinations or poor fishing output were draining or rotenone, followed by stocking the desired fish combinations. Bennett's research, highlighted earlier, was some of the first attempts to monitor fish stockings (Fig. 11.6). He examined a number of stocking combinations and showed that managers should consider the size and numbers of fish stocked so that food resources will be available to all stocked fish. Bluegill were often stocked prior to spawning in combination with Bass to provide prey for the larger fish as well as establish multiple-year classes in a pond shortly following stocking. This early focus on predator-prey interactions has been expanded upon in more recent INHS research evaluating stocking success.

Many studies have focused on the success of stockings by monitoring survival and growth of stocked fish. Initial studies emphasized the density and size of fish to stock including Largemouth Bass (7, 14, 15) and Channel Catfish (16, 17). These studies concluded it was important to understand the carrying capacity of a lake and the available prey. For Channel Catfish, predation by Largemouth Bass and angling mortality were major factors influencing

The value of long-term fisheries data—The initial fish collections of Forbes and Richarson (10) laid the groundwork for one of the most intensive and prolonged regional fish studies in North America and provides a unique opportunity for researchers to relate a century of biological observations to dramatic land use modifications and anthropogenic disturbances. The Fishes of Champaign County, Illinois (11) includes almost a century of research by INHS scientists at close to 30-year intervals. During this time period, much of Champaign County has been converted from marshes and prairies to well-drained and intensively cultivated land, which resulted in streams being modified by dredging, tiling, and straightening.

In 1899 and 1901, Stephen A. Forbes and Robert E. Richardson made 48 collections of fishes, including 65 species, in Champaign County while gathering material for their study The Fishes of Illinois (10). In 1928 and 1929, David H. Thompson and Francis D. Hunt revisited most of the former sites and completed a more comprehensive survey of the entire area with 132 Champaign County collections that included 73 species (12). The use of standardized sampling methods by Thompson and Hunt allowed them to make important generalizations regarding the distribution and abundance of fishes in small streams. In addition to collecting fish, they photographed many of their sites and made detailed field notes on physical characteristics (e.g.; depth, velocity) that later would serve as a benchmark to measure changes in stream habitat.

Thirty years after the previous study, R Weldon Larimore and Philip W. Smith undertook a third survey in 1959 and 1960 to investigate changes in aquatic habitats and fish distributions resulting from agricultural development and population increase in the county (Fig. 11.4). Newer collection techniques, such as the use of electric fishing gear, were incorporated to improve sampling efficiency and reliability (Fig. 11.5). In the third survey, they noted considerable changes in stream habitat as a result of dredging and other agricultural practices. Although the total number of fish species collected was the same as the previous survey, they found a significant drop in species richness per sample between 1928 (19 species) and 1959 (15 species). They attributed changes in fish assemblages to a rapid deterioration of water quality and land use effects (13). Results of this study contributed to the realization that management of stream fish populations depended on the management of stream watersheds.

In 1987 and 1988, Larimore and associates conducted a fourth survey replicating the same sampling methods and locations as in the 1950s (11). While some fish species previously recorded were not collected in their study, the total number of species stayed the same as the past two surveys due to the addition of non-native and stocked species, such as Common Carp, Walleye, and Northern Pike. A primary objective of this last study was to identify environmental variables controlling the structure of stream fish communities by utilizing geographical information systems (GIS) (see Chapter 3) to more accurately quantify instream habitat conditions. These data gave them insight into changes in watershed patterns that enabled them to make important watershed-level management recommendations such as implementing riparian buffer strips to improve stream water quality and protect fish community structure.

As is the case in many other areas of the U.S., the Champaign County area is currently experiencing a rapid increase in urbanization and industrial development. When combined with current fish surveys, the historical data collected from Champaign County streams highlight the value of long-term data sets and provide a unique opportunity to document fish community responses and impacts to streams in a region where the landscape has been transformed from native prairie to agricutural and urban.

Figure 11.4. Leonard Durham (left) and Weldon Larimore sampling on Jordan Creek.

Figure 11.5. Testing the electric seine, a sampling device that was developed at INHS to collect stream fishes.

Figure 11.6. Testing one of the early electroshocking boats.

survival. These studies resulted in the recommendation of not stocking Channel Catfish over 200 mm and the use of length limits to reduce mortality of smaller fish in order to produce a desirable fishery.

A series of studies examined using hybrids to increase the success of stocking in developing Crappie fisheries in small impoundments (18, 19, 20). Crappie stocking using Black and White Crappie is generally unsuccessful due to erratic recruitment. INHS research demonstrated that hybrid Crappie were easy to propagate, had high survival rates, and grew faster than their parental counterparts in management ponds, yet did not have the erratic reproduction due to reduced fecundity. These studies recommended stocking F_1 (first generation) fish because they exhibited higher growth and recruitment rates. In mixed populations, the hybrid Crappie showed similar growth rates as the parental fish yet had reduced recruitment rates, which avoided overabundance of offspring that could lead to reduced growth rates. Additional work with genetics of hybrids is discussed in the following Fish Conservation Genetics section.

More recent studies have focused on the mechanisms influencing stocking success of Walleye and the importance of lake specific characteristics (21, 22, 23, 24). They determined that fry and small Walleye were most susceptible to temperature changes and that mortality could be reduced if hatchery temperatures were close to lake temperatures and fish were slowly acclimated to them. Small fingerlings (50 mm) were shown to experience higher survival than fry and large fingerlings (100 mm) and were larger going into winter than large fingerlings. These studies also found size-specific growth and survival of Walleye were related to prey resources and predator density. These results have greatly influenced how Walleye stockings are conducted today throughout the country.

Substantial recent work has also been conducted on Largemouth Bass (25) and the reintroduction of Muskellunge into Illinois waters (26, 27). Researchers examined factors influencing the survival of young of year and age-1 stocked Largemouth Bass and determined that initial stocking mortality for Largemouth Bass was low. However, predation was found to be responsible for substantial mortality of stocked fish. Bluegill prey abundance was also an important factors influencing survival of stocked Largemouth Bass. Greater survival was shown for stocked Muskellunge with increased stocking size. Prey density was also shown to greatly influence the growth of Muskellunge. When prey was abundant, the medium fingerlings outgrew large fingerlings due to the longer duration in the lake; however, when prey was not abundant, the large fingerlings had the highest growth. Experience feeding on minnows also proved to influence growth, vulnerability to predation, and survival of Muskellunge and Tiger Muskellunge. Survival was highest for experienced fish, most likely due to increased predation on the naïve fish.

A synthesis of studies conducted at INHS and elsewhere have resulted in establishment of a framework for evaluating stocking success for a number of fish species (Fig. 11.7; 28). Wahl emphasized the importance that predators have on survival of stocked fish and how this can vary with the species being stocked, the size at stocking, as well as the composition of the predators in a system. The synthesis outlines how prey composition and availability can influence survival and growth. Abiotic factors such as temperature can also greatly influence initial stocking survival and growth of stocked fish. The framework emphasizes the importance of evaluation in the stocking process and using an ecological perspective when making stocking decisions. Wahl supplemented this publication with another regarding guidelines specific to Muskellunge (29) that highlighted the importance of predation and prey composition in determining the survival of stocked Muskellunge. These frameworks provide guides for making lake-specific stocking decisions and emphasize the factors that should be considered when fish are stocked. The results of Illinois Natural History Survey research has had and will continue to have a major influence on stocking strategies for fish and have increased the productivity of stocking efforts worldwide. Ongoing

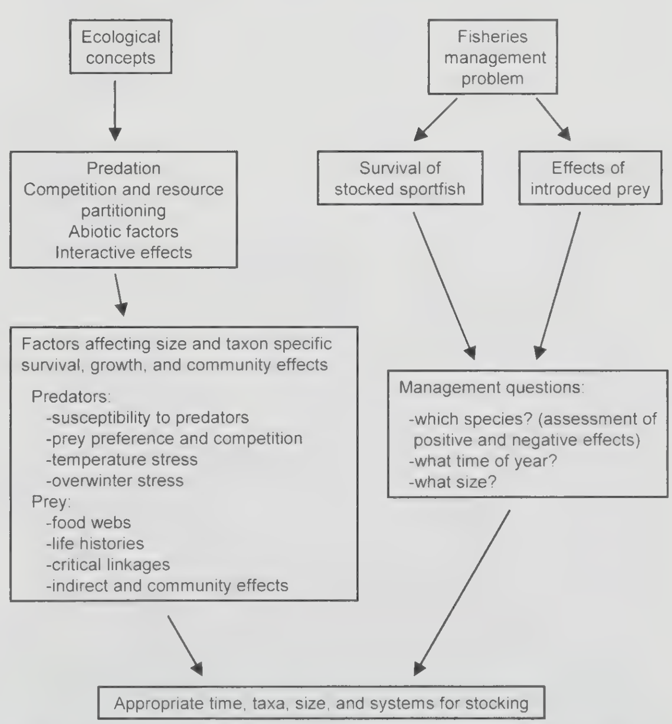

Figure 11.7. An ecological framework for evaluating the success and effect of introduced fishes. The framework integrates the relative importance of predation, competition, and abiotic factors for all life stages (28).

research will continue to affect management decisions in the future in order to optimize the use of hatchery resources in providing better fishing for anglers.

RECRUITMENT IN FISH POPULATIONS

"It is in fact hardly too much to say that fishes which reach maturity are relatively as rare as centenarians among human kind." — Stephen A. Forbes (1).

Unraveling the causes of recruitment fluctuations in fish populations has been, and continues to be, one of the central issues of both basic ecological research and applied fisheries ecology. Studies of fluctuations in abundance of exploited fish populations produced foundational ecological models by researchers such as Vito Volterra (30). Early in the scientific study of fish population dynamics, Johan Hjort (31) proposed that to understand the causes of fish population fluctuations, researchers needed to examine the survival of early life stages. Hjort's hypotheses concerning a critical period of mortality that fish must pass through during their first year of life before they can recruit into the adult population has led to decades of research on the early life stages of fishes and factors that affect their growth and survival. Since Hjort's time, new hypotheses and models have extended his ideas, and the study of fish recruitment has also been moved forward by innovations in technology and analysis. Despite over 90 years of research, our understanding of the mechanisms of fish recruitment is incomplete and our ability to predict year-class strength remains limited.

Fish recruitment has primarily been studied in marine systems, but the Illinois Natural History Survey has contributed to the study of recruitment of freshwater fishes. One important development in the study of fish recruitment and early life history has been the discovery that there are daily growth rings on the otolith bones of fishes (32). This discovery has provided researchers the means to determine the hatch dates and growth history of individuals collected during the first year of life. INHS researchers Miller and Storck (33) used known-age individuals to verify daily ring formation and calibrated ring counts by determining age at first ring formation for Largemouth Bass otiliths. This study made an important impact on both the promotion and refinement of the application of otolith daily marks to the study of the early life stages of freshwater fishes. Dimond and Storck (34) and Miller and Storck (35) used otolith daily marks to measure the effect of temporal variation in spawning dates on growth during early life stages. These studies determined that interspecific differences in the timing and duration of spawning are responsible for a considerable portion of the differences in size structure observed among taxa (34), and also documented that intraspecific differences in timing of spawning play an important role in producing variation in diet and growth observed among members of the same cohort (35). The techniques described in Miller and Storck (33) have been used extensively in studies of Largemouth Bass recruitment, a species of great ecological and economic importance throughout North America, and remain an important tool in ongoing projects designed to identify links between differences in hatch date and variation in growth, diet, and survival of largemouth bass individuals.

Hjort (31) and subsequent researchers (36) developed one of the leading hypotheses regarding fish recruitment—the extreme sensitivity of larval individuals to starvation means that those factors affecting prey availability during early life stages are the primary determinants of year-class strength. Although many scientists have found this hypothesis appealing, empirical demonstrations of the hypothesized relationships between prey availability during critical life stages and recruitment have been rare (36), and in fact, there is uncertainty regarding whether starving individuals die from lack of food or from increased vulnerability to predators. Jonas and Wahl (37) explicitly tested the relative importance of direct versus indirect effects of starvation and found that direct effects of starvation (i.e., not predation) were more likely to determine larval mortality rates of Walleye. Our understanding of the relationships among prey availability, growth, and survival during early life stages of fishes has been aided by other recent lines of research. These include quantifying the relative importance of different zooplankton taxa for larval and juvenile survival (38, 39) and testing the magnitude of competition for food resources between larval fishes (40, 41). This research has provided crucial information on how variation in the abundance of different types of zooplankton affects fish survival during sensitive, early life stages (38, 39). In addition, these research projects have detailed how the susceptibility of larval fish to starvation is related to body size and environmental factors, including water temperature (37, 41). Claramunt and Wahl (41) measured larval growth rates of three fish species (Bluegill, Gizzard Shad, and White Crappie) and sampled both abiotic and biotic variables across multiple populations in Illinois and found that most of the variation in growth rates was explained by abiotic factors such as temperature and lake morphometry. The specific biotic factors responsible for interpopulation variation in growth rates differed among study species. Experimental work has demonstrated how differences in prey availability and foraging abilities influenced the timing of ontogenetic diet shifts in Walleye (42) and how differences in predator morphology leads to differences in ontogeny between closely related species (43).

It has become clear that understanding the mechanisms responsible for recruitment variation requires the synthesis of biological information across a variety of environmental conditions. When Parkos and Wahl (44) reviewed literature related to largemouth bass early life history and recruitment, they found that critical periods of mortality varied among systems that had different environmental conditions. For example, researchers have found that mortality resulting from overwinter starvation was much less important to Largemouth Bass recruitment in Illinois reservoirs than for populations at more northerly latitudes (45) and variations in rainfall amount (and associated amount of flooded vegetation) impacted year class strength (46). Parkos and Wahl (44) developed a conceptual model that illustrated how different abiotic and biotic factors influenced recruitment depending on the stage of offspring development that year-class strength was set for a particular population (Fig. 11.8). Support for that model

has come from Santucci and Wahl (47) who evaluated the effects of predation and size-selective winter mortality on recruitment of three year-classes of a Bluegill population and found that, contrary to typical models of fish recruitment, individuals from later spawning events had higher growth and lower mortality than early-spawned individuals. By examining recruitment across multiple years, they were able to determine that Bluegill recruitment was the result of cumulative mortality throughout the first year of life rather than mortality during one critical life stage (47). Realizing that the factors responsible for variation in growth and mortality can affect multiple life stages, Hoxmeier et al. (23) examined the multiple factors hypothesized to affect Walleye growth and survival during the first year of life. This study evaluated the growth and mortality of three different life stages from 15 populations in each of 7 years, and found that the relative importance of factors (such as predation, invertebrate prey, fish prey, and temperature) varied among size classes of Walleye, demonstrating the value of assessing multiple life stages when studying recruitment dynamics. Long-term studies are needed to assemble an effective understanding of, and predictive framework for, recruitment variability in fish populations. As ecologists and natural resource managers face the ramifications of climate change for future of fish populations, large data sets that encompass a variety of systems and conditions will also be important for predicting how fish populations are likely to respond to their changing environment.

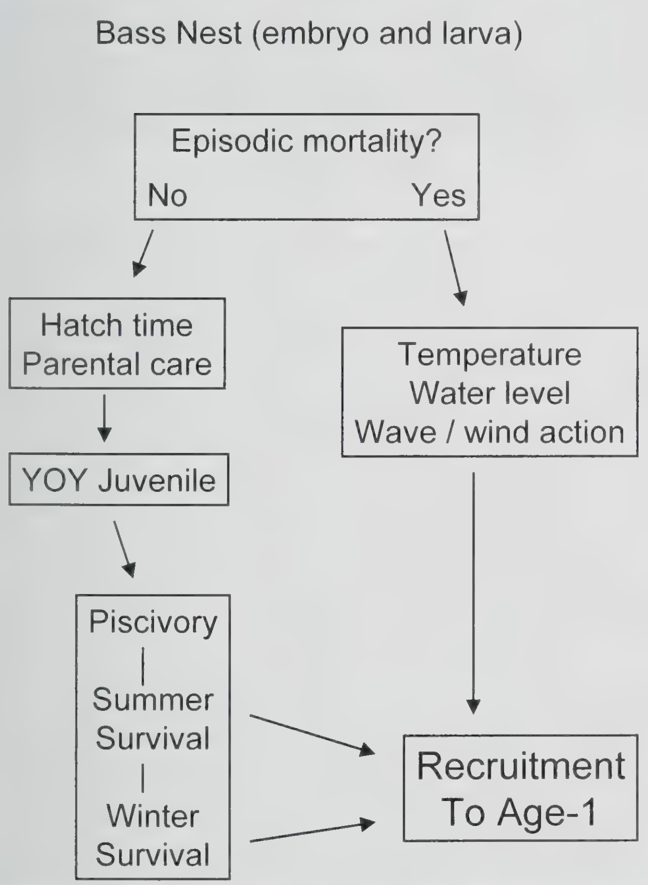

Figure 11.8. Conceptual model of Largemouth Bass recruitment to age-1. Important developmental stages during the first year of life are in bold type in boxes. Solid arrows are pathways of recruitment to first annulus formation, and arrows go through variables that are important to survival between life stages. If episodic mortality occurs when either embryos or larvae are in the nest, dynamics during these life stages determine recruitment strength. Otherwise, postlarval young of the year juvenile survival sets recruitment to age-1. (modified from 44).

Molecular techniques have the potential to greatly improve our understanding of many aspects of fish recruitment by enabling researchers to assess the contribution of individual fish to year-class formation (e.g., 48). By conducting genetic parentage analyses of surviving offspring collected at a particular developmental stage, researchers are able to determine how specific traits of individual fish affect reproductive success, and then how the reproductive success of individual fish affects population-level recruitment. For example, a long-term study of Smallmouth Bass reproduction in Ontario has found that the total number of fry surviving the parental care period is a good predictor of the number of 1+ offspring observed the following summer. However, without molecular techniques, there is no means of identifying which males' offspring survived to make up the year class. Molecular parentage analyses have already refuted the long-standing assumption that many reproductive individuals make approximately equal contributions to fish population recruitment; every study conducted to date has found that a fraction of the reproductive individuals produce a disproportionate number of the offspring surviving at later life stages (48, 49, 50, 51). If males with particular traits are producing a large portion of each year class, then ensuring strong recruitment may largely depend on protecting these males from angling during the parental care period. Although molecular techniques are just now being applied to studies of fish recruitment, they will allow researchers a direct means of investigating how individual variation within a population affects the persistence of exploited fish populations. All of the studies above have illustrated the value of considering recruitment as a process embedded within a web of community interactions and ecosystem dynamics. Gaining a comprehensive understanding of the mechanisms responsible for fish recruitment variation continues to be a challenge for fisheries managers and scientists. However, this ecological process is fundamental to the management and conservation of aquatic resources. Researchers at INHS, along with those at other institutions, have made important contributions to the study of fish recruitment in the past, and will continue to play a central role by incorporating innovative approaches ranging from the small (individuals, genes) to the large scale (communities, ecosystems) in current and future investigations of fish population dynamics.

> "He will thus be made to see the impossibility of studying completely any form out of relation to the other forms; the necessity for taking a comprehensive survey of the whole as a condition to a satisfactory understanding of any part. If one wishes to become acquainted with the black bass, for example, he will learn but little if he limits himself to that species. He must evidently study also the species upon which these depend. He must likewise study the species with which it comes into competition, and the entire system of

conditions affecting their prosperity; and by the time he has studied all these sufficiently he will find that he has run *through the whole complicated mechanism of the aquatic life of the locality, both animal and vegetable, of which his species forms but a single element.*"
—Stephen A. Forbes (1).

INVASIVE SPECIES—THE EXAMPLE OF CARP

"For years, and seemingly to my misfortune, I was held responsible for the introduction and defense for this much maligned fish, and I have had plenty of newspaper notoriety as its advocate, but I have emerged from it triumphant, as it is to-day the universal opinion of every responsible fish dealer on the Illinois River that the carp was the best gift ever made by the United States Fish Commission to the people of the State" —S.P. Bartlett (52).

Although some invasive species are the result of accidental introductions, many species are intentionally brought in for economic reasons with little regard for the ecological implications. The Common Carp (*Cyprinus carpio*) is an excellent example of this type of intentional introduction of a species that was brought in to establish a commercial fishery, but has since become an ecological nuisance. Unfortunately, invasive species are now one of the major problems facing aquatic ecosystems (53). Aquatic ecosystems are particularly affected by invasive species and appear to be more vulnerable to invasions than terrestrial systems (53, 54).

The decision to introduce Common Carp was based largely on it's potential as a commercial fishery, particularly its ability to ship easily and sell in the big cities of the Eastern United States (52, 55). The introduction of Common Carp into Illinois was a contentious decision (52). There were objections and allusions to potential effects of Common Carp on other species through "roiling" of the water, destroying vegetation, having negative effects on Perch and Buffalo, and potentially disturbing the spawning of black basses. Such claims were largely dismissed with little in the way of scientific evidence (55). Ultimately, however, the fish were introduced in Illinois as advocated for by Dr. S.P. Bartlett of the United States Fish Commission, who was stationed at Quincy, Illinois. The promotion of Common Carp in Illinois waterways continued and they became widely established throughout the state.

It wasn't until 100 years later that scientists from INHS, led by Joe Parkos, Victor Santucci, and David Wahl, assessed the effects of Common Carp on ecosystem dynamics in a quantitative way. Using experimental enclosures, they demonstrated that Common Carp decrease aquatic macrophytes, increase turbidity and phosphorus concentrations, and have stronger negative effects on benthic invertebrates than native benthic fishes (56). These findings verify some of the early criticism and also highlight additional concerns regarding carp introductions not taken into account during early discussions. The next step in accessing the effects of Common Carp on native ecosystems is to move from small experimental systems to large whole-lake systems. In addition to work with the Common Carp, INHS was also involved in some early experimental work with three Asian carps, the Grass Carp (*Ctenopharyngodon idella*), Silver Carp (*Hypophthalmichthys molotrix*), and Bighead Carp (*Aristichthys nobilis*) (see Chapters 9 and 12). Dr. Homer Buck used experimental ponds at the Sam Parr Biological Station (Fig. 11.9) to examine the use of swine in the polyculture of different species of Asian carp and North American fishes (57, 58). With four Asian carp species recently released in to the Mississippi River and firmly established throughout the state, a major question for current and future researchers is what can be done to mitigate their effects on our aquatic ecosystems.

Figure 11.9. Sam Parr Biological Station in 1990s.

STUNTING AND POPULATION SIZE STRUCTURE IN FISHES

Stunting is a common problem in fish populations and is defined as a population dominated by smaller individuals. Slow growth rates often result in a small size structure with few fish that are desirable to anglers. One species of special interest has been the Bluegill Sunfish, *Lepomis macrochirus,* one of the most popular sportfish species in North America. Unfortunately, over the past 50 years there has been a decline in Bluegill size and many stunted populations that consist primarily of smaller individuals now exist. On average, adults from stunted populations are 1 to 2 inches shorter than those from nonstunted populations.

Some of the earliest research on stunted growth in Bluegill was conducted in the 1930s and 1940s by Homer Swingle at Auburn University. Swingle postulated that stunting could be prevented if proper prey to predator biomass ratios were maintained. The theory that the maintenance of proper "balance" could prevent stunting lasted through the 1950s until INHS researcher George Bennett began to challenge Swingle's theories (Fig. 11.10). Bennett pointed out that stocking history dictated prey to predator biomass ratios and "balance" could not explain the occurrence of proper size structure in some populations (9). Since Swingle and Bennett's early research on growth, additional research has shown that other mechanisms that may influence Bluegill size structure include the over-exploitation of larger fish (59, 60) and inadequate food supply (61, 62).

Figure 11.10. George Bennett (right) and R.W. Larimore examine fish during a food habits study.

Beginning in the mid-1990s, mechanisms causing stunting in Bluegill populations again became a focus. Illinois Natural History Survey researchers found that not only do Bluegill in stunted populations mature at a smaller size, but they also mature at a younger age than those that are in nonstunted populations. The size and age at maturation of Bluegill is heavily influenced by the social structure of the population. For example, smaller mature male Bluegill invest less energy into gonad development and nest less frequently when raised in the presence of larger mature males as compared to in their absence (62) and juvenile Bluegill from both stunted and nonstunted populations also matured at a higher rate in the absence of large, mature males (63, 64). Further research determined that resource availability had a greater influence on Bluegill growth whereas social structure had a greater influence on the timing of maturation (65). Collectively, this research has shown that in order to maintain a large Bluegill size structure, it is essential to protect larger males because their presence delays the maturation of younger fish and forces them to mature at a larger size than they do in populations that have a lower density of mature fish. Social structure is not the only factor that influences Bluegill size structure and other factors that may contribute to stunting. For example, Bluegill grow faster in lakes that do not contain Gizzard Shad (66).

THERMAL ECOLOGY AND ITS APPLICATION TO FISHERIES: THE LAKE SANGCHRIS STUDY

Environmental temperature plays an important role in governing several behavioral and physiological processes in cold-blooded organisms such as fish (67, 68). For fish, hatching success of eggs, growth, survival, and optimization of physiological processes are all driven by environmental temperature (69, 70, 71). Fish are subjected to continual thermal changes as their aquatic habitats are thermally dynamic both spatially and temporally. Given this state of continual flux, fish have adapted a wide range of thermal tolerances for several life history processes to cope with their environments (72) and deviations outside of their thermal ranges can have serious negative consequences.

Understanding the thermal ranges of several species of fish became progressively important in the 1960s due to increasing demands of aquatic resources for use in electrical generation facilities, which discharge abnormally hot water back into aquatic systems (73). Discharge of hot water back into aquatic systems was viewed as "thermal pollution" because of potential negative effects hot water has on reproduction, migration, growth, and physiology of aquatic organisms (74, 75, 76). These negative effects of hot water discharge were addressed in the Clean Water Act which has a specific section (316(a)) regarding thermal loads (see 77). Early studies addressed thermal discharges into rivers whereas fewer studies quantified the impact of thermal discharges in reservoirs.

Since the 1960s, 12 reservoirs have been constructed in Illinois to provide a continual water source for electrical generation power plants. These power plants demand a large volume of water for cooling processes associated with both nuclear and coal-powered electrical generation (Fig. 11.11). The thermal effects of waste heat from power plants on reservoir fish populations were poorly understood immediately following the construction of cooling lakes but were important to fisheries managers because 11 of the 12 cooling lakes were open to sport fishing. Concerns about waste heat included temperature limits for reproduction, effect on primary production, composition of the biotic community, cold shock associated with power plant shutdown, and oxygen consumption of fishes with respect to increased temperature (78).

To better understand the impact of waste heat on fisheries, Illinois Natural History Survey researchers (led by R.W. Larimore and J. Tranquilli) began in 1973 a first-of-its-kind intensive study of fish populations and related aquatic components of Lake Sangchris, a power-plant cooling lake in central Illinois. This work documented many biologically interesting results such as earlier spawning dates and higher fish production and diversity (79). It was also noted that localized benthic invertebrate populations were not negatively impacted by warm water discharge. These discoveries along with others demonstrated that the thermal

Figure 11.11. Thermal effects of Newton Power Plant during winter (photo by L. Kim).

waste produced by the power generating plant was not a limiting factor to biological life and may even be beneficial to the productivity of Lake Sangchris. Findings from the Lake Sangchris study have allowed fisheries biologists throughout the country to effectively manage such unique systems.

Thermal changes not only have effects on fish populations, but can also alter how individual fish physiologically respond to and recover from stressors (80). Future research at the Illinois Natural History Survey will be aimed at understanding how rapid changes in temperature instigate stress responses from fish, which will allow better management decisions regarding fish stocking, water quality assessment, fishing tournaments, and other fisheries management components. By evaluating thermal ecology at this scale, fisheries managers can better understand how fish populations are affected by thermal dynamics and how individual members of populations withstand specific thermal effects. Understanding the interaction of physiology and thermal dynamics will not only assist in fisheries management decisions, but will also provide insight for potential impacts of thermal changes associated with global climate change on fisheries throughout the world.

FISH CONSERVATION GENETICS

While the study of genes and their influence on an organism's biology has attracted the attention of scientists since the early 1900s, fish genetics research began at the INHS with William F. Childers' (Fig. 11.12) longstanding interests in hybridization between species of sunfishes, a process that occurred naturally in the waters of Illinois. Several groundbreaking studies (81) compared the morphological characteristics of these hybrids, as well as their growth, survival, and reproductive output in an assessment of their usefulness as fisheries management tools. These studies allowed workers to produce F1 hybrids among distantly related species that would not spawn together naturally. Their work on forming hybrids between Largemouth Bass females and Smallmouth Bass males (only possible in the laboratory), the now somewhat infamous "meanmouth bass," created interest in the fisheries management community for using such new technology to produce novel fish (82). This interest, much to Childers' dismay, continues today and has been the source for genetic conservation issues on a widespread scale.

Figure 11.12. Aquatic Biology Staff at Fin and Feather Club, Dundee, IL, September 22, 1960. (Left to Right). Larimore, Childers, Hansen, Thoits, Starrett, Hiltibran, Fritz, McGinty, Buck.

Since the 1970s, the tools available to genetic researchers have greatly expanded and a multitude of scientists and students have used molecular genetic approaches to investigate a variety of questions related to fisheries biology, fish ecology, and evolution. These efforts have been classified into four areas of contribution and are summarized below.

Hybridization

To examine the suitability and effectiveness of combining the genomes to two different species, a genetics research group at INHS, beginning in the mid-1970s, went beyond comparative morphological studies by using a wide variety of in-vitro hybrids. These studies documented the inverse relationship between survival and the level of alteration in the developmental patterns of gene expression during early development (83, 84, 85, 86). They also concluded that divergence in regulatory genes was more important for adaptation and speciation than divergence in structural genes, a concept that continues to spur evolutionary research today. In addition, field experiments on assortative mating and reproductive success in crappie (*Pomoxis*) species (87) coupled with theoretical work on how hybridization impacts parental lineages provided a conceptual framework for how mate choice and parental genetic distance impact fitness of offspring through generations (88).

Population Genetics

A seminal paper published in 1983 (89) redefined not only the genetic status of Largemouth Bass throughout its range within the US, but also documented the fallout from the past indiscriminant stocking programs of many state agencies. These molecular genetic results documented the recent influx of genetic material from populations in Florida as a result of deliberate management efforts in a number of states. This paper also was one of the very first to introduce the concept of outbreeding depression (Fig. 11.13) (the mating or crossing of less related individuals that results in less fit or less healthy offspring) as a negative consequence of hatchery stocking programs. A series of papers documenting the unwanted introgression that occurs from stocking programs and what the implications of such programs were for our native fishes (72, 90, 91, 92, 93) brought the issue of conservation genetics to the forefront of consideration by many management agencies. In fact, the genetic integrity of entire species of black bass, genus *Micropterus*, were shown to be at risk, even as their evolutionary relationships were still being discovered (94, 95). Even in the face of information documenting the genetic differences among populations and species, there are still active programs that are promoting their human-induced mixture, thus providing evidence that some natural resource management agencies continue to base their thinking on an agricultural model rather than an evolutionary one.

Latitudinal Variation

A natural outgrowth of the early genetics work was to understand how major selective pressures might influence the intraspecific variation in life histories of fishes. Arguably the most influential selective pressure exerted on cold-blooded organisms is latitudinal variation—more specifically, the thermal regime gradient. Temperatures experienced by fishes affect all aspects of behavior and physiology, including locomotion, immune function, sensory input, foraging rates and ability, courtship, reproduction, metabolism, and growth. Because many fishes are distributed across a broad latitudinal range, geographically and oftentimes genetically distinct populations and stocks have evolved under varying thermal conditions associated with this latitudinal range (89). As a result, these local populations and stocks likely have developed differential, and presumably adaptive, physiological and behavioral responses to their thermal environments (89).

A genetic evaluation of Largemouth Bass from throughout the species range confirmed the genetic distinction between the two described subspecies of Largemouth Bass—Northern and Florida (now described as distinct species [94]), but also more importantly revealed latitudinal distribution patterns of a number of genetic markers (84). These markers were shown to strongly correlate with numerous environmental variations associated with latitude (96), consistent with the hypothesis that genetic differences at specific enzyme loci can confer different degrees of fitness in different thermal environments. During the decades to follow, INHS research examined numerous life history differences such as spawning period, growth, and survival among populations and stocks of Largemouth Bass and Florida Bass (92, 97, 98). In addition, swimming performance, routine oxygen consumption, activity levels, and cardiovascular performance were examined among Largemouth Bass populations spanning a latitudinal gradient in the upper Midwest (99, 100, 101, 102). In combination, these sets of studies provide strong evidence not only for local adaptation but also for outbreeding depression, especially as they relate to the impacts of stocking.

During this same time period, other researchers were examining stock-specific bioenergetics components and exploring potential latitudinal associations with them. Consumption, growth, and metabolism were evaluated for six populations of Muskellunge (103) and five populations of Walleye (104), with populations from both studies spanning intraspecific latitudinal gradients. Both studies demonstrated population-specific differences in measured variables, but results were not always consistent with latitudinal and thermal gradients. Most recently, intraspecific variation in behavioral and life history attributes has been examined for three stocks of muskellunge in a common field environment using telemetry approaches (105). These findings provide support for considering population- and stock-specific rates, especially when using bioenergetics models.

Adaptation

The thermal ecology of fish, particularly as it pertained to the heated effluents that were being produced from power plants, was an important issue of the 1970s and 1980s, because of how added heat may impact locally adapted populations. Using Largemouth Bass as the study organism, studies documented the level of variation among populations in this species' thermal tolerance (106), thermal preference (107), and developmental rates (96), as well as how different populations of bass differed biochemically in how they reacted to temperature (96, 108). These studies, together with the population genetic surveys described above, formed the most important body of evidence for warmwater fishes in support of the Stock Concept. The idea that different populations of fish had adaptations to their environments that made them genetically distinct from one another was finally becoming engrained into the thoughts of fisheries biologists. What remained a debate (and still does to some extent today) was the relative size of the impact of mixing divergent populations in the wild (91, 109). Two important long-term experimental studies documented in the wild the negative fitness consequences of mixing wild stocks of largemouth bass (97, 98), providing for the first time among fish species, evidence in support of the Optimal Relatedness Concept (Fig. 11.13) and documenting the existence of outbreeding depression (the loss in fitness among offspring of too distantly related parents). Subsequent experimental studies with captively bred P1, F1, and F2 generations of parental lines and interstock hybrids have shown two potential mechanisms for the expression of such fitness losses, a breakdown in disease fighting machinery (110) and altered cardiovascular performance (99, 111). In addition, a 30-year study documenting the heritability of vulnerability

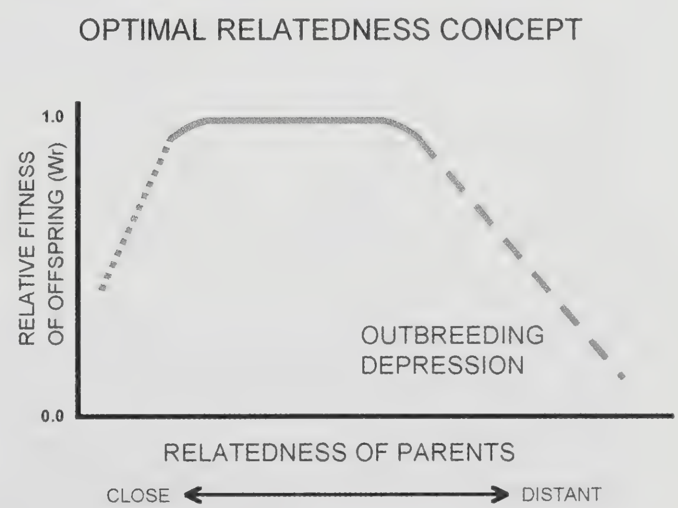

Figure 11.13. Optimal Relatedness Concept. This figure demonstrates the relationship between the relative fitness of offspring (Wr) and the genetic relatedness of its two parents. Offspring fitness for mating pairs in the same or reasonably closely related populations suffer no fitness loss and, therefore, have a Wr = 1.0. Offspring of parents that are too closely related do experience a fitness loss (termed inbreeding depression) because of the increased chances for inheriting deleterious recessive alleles from two closely related individuals (heterozygous carriers). Conversely, offspring of parents that are too distantly related also experience a fitness loss (termed outbreeding depression), in this case it is because of the breakdown of co-adapted gene complexes or the introduction of maladaptive alleles.

to angling (112, 113) illustrates the level of artificial selection that is being placed on our wild fish populations by recreational anglers as well as how that selection is changing the behavioral and physiological characteristics of entire populations (112). How the angling and management communities deal with this new information will be very interesting!

EFFECTS OF ANGLING ON FISH POPULATIONS

Early in their history, aquatic research programs were primarily focused on inventories of aquatic fauna, and little scientific attention was paid directly to the relationships between fish populations and angling. This fact may be largely attributed to a general understanding in the early days of fisheries management that most fish species produce an abundance of young, of which only a few survive to adulthood (114). This strongly held view supported a fisheries management approach akin to cropping systems, where emphasis was placed on maximizing production (e.g., via stocking) to increase standing crop, and on harvest as a means to provide a resource, whether food or recreational value, to humans.

While the effect of angling on fish populations was not explicitly studied early in the twentieth century, the general understanding among fisheries personnel was that Largemouth Bass populations were declining (14). Bennett implies that this trend was the inspiration for the growth of state hatchery systems as well as the implementation of closed bass angling seasons, minimum size limits, and daily creel limits. These fishing restrictions hint that over harvest by anglers was the suspected mechanism causing Largemouth Bass populations to fail. In the late 1930s, Bennett conducted the first studies at the INHS to directly examine the impacts of fishing on fish populations. Bennett utilized hoop net sampling and a creel census to substantiate suspicions of over-fishing on Onized Lake near Alton, Illinois (6).

Around this same time, Ridge Lake, an impoundment of Dry Run Creek near Charleston IL, was opened to the public in 1942 and a complete creel census was begun (114). The Ridge Lake creel census continues to the present and represents one of the longest continuously running fish censuses in the country. In the 1950s, a creel census was also begun on Lake Chautauqua, a bottomland lake associated with the Illinois River near Havana, Illinois (115). In fact, assessing angler harvest played an important role in measuring the impact of angling on fish populations throughout Illinois in the twentieth and twenty-first centuries, with surveys conducted at various times on numerous lakes and rivers (15, 116, 117, 118), including Lake Michigan (119). This work has raised the profile of angler-related data in the observational and experimental research of Illinois fish populations. These annual surveys provided fisheries managers with critical data to support various management actions, including the setting of length and bag limits as well as supplemental stocking strategies.

Although early research examined relationships between angling activity and fish abundance and size structure, research did not address mechanistic pathways by which angling impacts fish populations. In a letter to "The Illinois Sportsman" magazine, however, Bennett (120) specifically identified the angling of nesting Largemouth Bass as potential problem for future cohorts of bass. The spring of 1940 was apparently late to arrive, delaying the onset of the spawn. Opening of the Largemouth Bass angling season was to coincide with the spawning and nesting season of the species, prompting Bennett's plea:

> *"As all fishermen know, these fish are most easily taken when nesting... (and) the loss of each adult represents a loss of several thousand young fish. This loss will not be felt, however, until about 1942 or 1943, when these young fish would have reached legal size. It is suggested that sportsmen be requested to refrain from bass fishing until two weeks after the legal opening date. This will enable the fish to bring off a normal hatch and protect the young for a short period after they leave the nest."*

Bennett's letter is fascinating in that it demonstrates a common understanding of parental care behavior and its importance to the survival of young, and in turn how the surviving young determine the size of future adult populations. It wouldn't be until the 1970s that the concepts on which Bennett based his plea would begin to be rigorously tested (121, 122, 123, 124). Bennett's letter goes one step further, connecting angling to the disruption of parental care and the effect of that disruption on recruitment and population size—an area of research that had become of interest among scientists in the 1990s and continues through the present day.

Investigations into the specific impacts of angling on life history, behavior, and ecology of Illinois game fish have focused primarily on Largemouth Bass, and to some degree Smallmouth Bass, in the last 20 years. These studies have examined a wide range of topics, including vulnerability to angling (125, 126), the physiological effects of the angling event (127, 128) and individual reproductive success (129). For example, Philipp et al. (129) found that when a nesting male bass is angled away from his brood, holding time was critical in determining whether the male returned to the nest to continue guarding his brood or abandoned the nest entirely. As Bennett cautioned sportsmen to not interrupt spawning largemouth bass in 1940, researchers today have supported Bennett's assumptions with scientifically rigorous studies.

As more detailed investigations into the effects of angling were being conducted, Largemouth Bass were solidly one of the most popular game fish in North America (130, 131). This popularity led to a rise in the number and size of angling tournaments (Fig. 11.14) held by small local fishing clubs as well as large sponsored organizations offering lucrative prizes to winners of competitive fishing tournaments (132, 133). Researchers began investigating the physiological effects of tournament practices such as the use of live wells, weigh-ins (Fig. 11.15), and release boats, as well as the physiological effects of the angling event itself (134). Specific management recommendations have included minimizing temperature changes and air exposure during tournament weigh-ins (135). The results of these studies

have offered tournament and nontournament anglers alike important information on how to best care for the resource while still enjoying their favorite pastime.

The scope of research relating angling to the health and sustainability of fish populations continues to grow today. Building upon a foundation established by research over the last 20 years, INHS scientists are now investigating how angling may influence fish populations on evolutionary scales (i.e., reduced aggression due to removal of most aggressive and therefore catchable fish), exploring how individual-level effects (i.e., nest abandonment after angling) may combine to affect entire populations, and hypothesizing how exploitation (over-fishing) may alter population size structure (136). As this work continues, the intricate connections that determine how angling can affect fish populations will provide scientifically rigorous conclusions that will inform management decisions designed to maintain sustainable fish populations (Fig. 11.16).

Figure 11.14. Anglers prepare for the start of a Largemouth Bass fishing tournament on Lake Shelbyville.

Figure 11.15. Anglers bring their catch to a central location during a typical weigh-in following a Largemouth Bass tournament. In response to the need for quantitative evaluation of both the biological effects and identification of causal factors associated with the negative impacts of competitive angling, a considerable body of literature has been published on initial and delayed mortalities. Excessive stress, implicit of high initial and delayed black bass mortality, has been correlated with hooking and landing, water temperature, live-well conditions, fish size, number of participants and teams, and tournament procedures that cause stress from handling.

FOOD WEB, COMMUNITY AND ECOSYSTEM INTERACTIONS

The history of fisheries research in general reveals a progressive shift in focus from studying fish populations as isolated groups towards a consideration of the interactions of fishes with other parts of the aquatic community and environment. Early fisheries science was hampered by a general ambiguity towards theoretical ecology (137) while fisheries researchers have claimed that theoretical ecologists remain "…aloof from the real world and ignore the prior work of fisheries biologists" (137, 138). The rift between theoretical ecology and fisheries has been slowly narrowing, largely due to the efforts of forward thinking researchers (including INHS scientists) who have recognized the value that each discipline can bring to the other.

An example of combining theoretical ecology and fisheries science is the elucidation of the trophic cascade (transfer of energy between different levels of the foodchain) in freshwater lakes (139). This major ecological paradigm states that predation reduces planktivorous fish releasing large bodied zooplankton from predation, which in turn heavily graze and reduce the standing biomass of phytoplankton (Fig. 11.17). Indeed, understanding the role of predation has led to application of theory in lake management, as trophic cascades have proven useful in lake rehabilitation. The reduction and control of primary productivity by piscivore (fish predators) introduction has been shown to increase water clarity and dampen the effects of nutrient loading in northern lakes that previously lacked top piscivores (140, 141). Research into trophic cascades has also significantly added to the understanding and awareness of the ecology of fish introductions.

Figure 11.16. Matt Diana (front) and Dave Wahl (back) of INHS operating modern electrofishing boat on Lake Shelbyville.

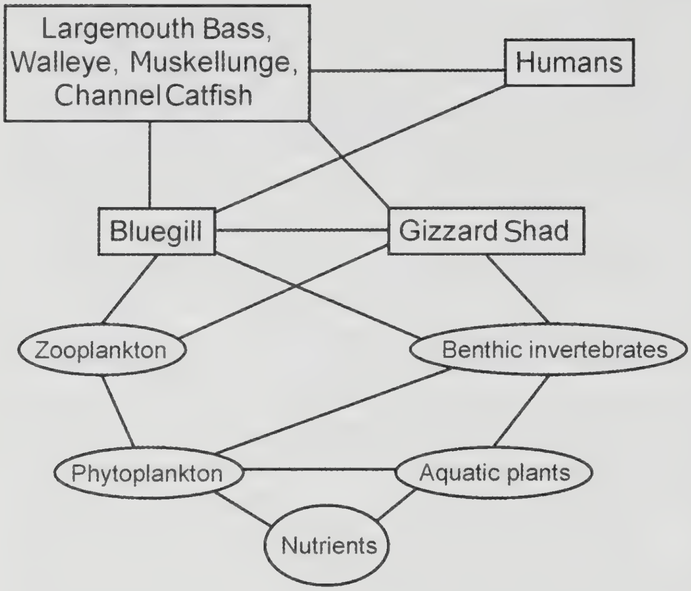

Figure 11.17. Example of complex food-web interactions common in many lake ecosystems among top predators (piscivores and humans), secondary consumers (Bluegill and Gizzard Shad), primary consumers (zooplankton and benthic invertebrates), primary producers (phytoplankton and aquatic plants), and nutrients.

INHS research on fish introductions has mirrored the larger evolution of fisheries ecology. Early work reflected the paradigm of viewing a fishery in an isolated context, primarily concerned with fluctuations in fish production and yield (142). Research into fish introductions in the past two decades has evolved to focus on the effects of ecological variables on the success of sportfish stocking, embracing Forbes' holistic view of food webs (See Evaluation of Fish Stocking Success). These papers emphasize the value of applying theoretical ecology to fisheries science and management by bringing our understanding of fisheries into a community context.

Currently data are being collected on a number of lakes across Illinois, examining various aspects of community response to stocking Largemouth Bass and Muskellunge. These whole-lake experiments are unprecedented in their scope of replication (a common criticism of whole-lake experiments) and their potential to evaluate the prevalence of trophic cascades in lakes with existing predator populations. Many questions exist about the community effects of fish stocking and introductions (143, 144) and those being evaluated include differences in effects in lakes with Gizzard Shad (*Dorosoma cepedianum*) and Bluegill Sunfish (*Lepomis macrochirus*) prey bases, effects on total piscivore biomass, and changes in the predator:prey ratio in the community.

Several aspects of midwestern reservoirs are expected to make them less susceptible to trophic cascades than the northern boreal ecosystems studied by Carpenter and Kitchell (141). For example, Illinois lakes contain prey species like Bluegill Sunfish and Gizzard Shad that have been shown to be less vulnerable to predation than the smaller minnows (family Cyprinidae) of northern lakes (145, 146) (Fig. 11.18). Top predators in Illinois reservoirs are also limited by the maximum sizes of their mouths when feeding on deep bodied forage like Bluegill Sunfish and Gizzard Shad, thus creating size refugia for those species from predation (147). In addition to reduced vulnerability to predation, Gizzard Shad are omnivorous and have been shown to regulate food webs from the middle out, or intermediate trophic position, negating the effects of cascades (Fig. 11.17, 148).

It remains unclear, however, how the general enhancement of predation pressure by increasing piscivore diversity and biomass may affect Illinois lakes with differing prey populations. Differences may also exist among piscivores, with Muskellunge able to exploit size classes of Bluegill Sunfish and Gizzard Shad too large for Largemouth Bass. Introducing top predators like Muskellunge without understanding the ecological effects may have unintended consequences to existing aquatic communities and fisheries. The literature contains many examples of fish introductions having negative effects on receiving waters (144). For example, the introduction of Smallmouth Bass into headwater lakes in Ontario has caused changes in food web structure and negatively affected native Lake Trout (*Salvelinus namaycush*) (149). It is unknown whether these changes in food web structure are reversible, therefore it is paramount to understand the consequences of fish introductions and exercise caution in any stocking program. Intensively studying the community of various Illinois lakes before and after Muskellunge and Largemouth Bass stocking will reveal how these predators may differ in ecosystemwide effects. In addition, such studies can help us understand other ecological theories such as the lumping of all predators into a single tophic level. Multiple predators may interact resulting in nonadditive effects of facilitation or interference among species (Fig. 11.19). From a prey's perspective, combined predator effects on shared prey may not be predictable by individual predators. These studies continue advancing Forbes' idea that predation is a major process in the "harmonious balance of conflicting interests" in food webs.

Fisheries science needs to continue expanding from species-specific objectives to incorporate the interconnected view of communities that Forbes expounded. Management goals focused on particular species will be more successful when the processes structuring communities and ecosystem processes are part of management strategies. Recently

Figure 11.18. Wet laboratory at the Kaskaskia Biological Station used to evaluate predator-prey interactions of fishes.

researchers have proposed a bi-directional relationship between communities and ecosystem processes and a key debate is the importance of biodiversity to ecosystem processes, specifically seeking to understand how changes in species composition, distribution, and abundance influence ecosystem properties (150, 151). Because fisheries management practices alter community structure, understanding the bi-directional link between fish diversity and aquatic ecosystem processes at multiple trophic levels is necessary.

In addition, combining ideas of biodiversity and ecosystem function to address the conservation issue of exotic species invasions is needed. Understanding the ability of native biodiversity to buffer the effects of invasive species could be important as local biodiversity represents an important line of defense against the spread of invaders (152). Aquatic systems have been invaded and heavily impacted by a variety of taxa from carps to crayfishes to mollusks (see Chapters 9 and 10) and actions to prevent and mediate those impacts are needed.

CONCLUSIONS

Throughout this chapter we have introduced a number of major themes that have developed in fisheries science, many of which were initiated and fostered at the Illinois Natural History Survey. These contributions began with the pioneering studies of Forbes and Bennett and continue to the present; the foresight and influence that these two individuals have had on the history of fisheries science is quite remarkable. Since Forbes' time, changes in fisheries science have been numerous. Aquatic ecosystems in the U.S. and throughout the world are changing rapidly due primarily to effects from human populations. Fish communities in Illinois and across the U.S. have experienced many extirpations and introductions. Where species such as Common Carp were once widely introduced without regard for the implications, we are now concerned about effects on ecosystem processes. Even for sport fish species, interest has shifted from optimizing hatchery production to consideration of characteristics of recipient waters, including effects on survival of stocked fish, effects on the genetic integrity of native stocks, and implications for the remainder of the aquatic ecosystem. Increased understanding of the ecology of fishes and the aquatic systems in which they reside has also had important implications for fisheries science and how we manage these resources. Where management problems such as stunting in fish populations initially focused on the role of angler harvest and predator populations, we now understand the role of population social structure in influencing size structure. Similarly, knowledge of the implications of angling on nesting success in fishes have changed the way we make management decisions on issues such as closed seasons, harvest regulations, and fishing tournament practices.

Figure 11.19. Experimental mesocosms at the Kaskaskia Biological Station used to evaluate food web interactions in aquatic ecosystems.

Illinois has a diverse assemblage of freshwater habitats within it's borders, ranging from small ponds and streams to reservoir and medium sized rivers to Lake Michigan and the Illinois, Kaskaskia, and Mississippi rivers. The diversity of aquatic habitats and fauna has inspired a considerable amount of research on the ecology of a number of fish species and aquatic ecosystems. The Illinois Natural History Survey has taken an important role in studying the ecology of numerous fishes of economic and ecological importance to the world. In addition to benefiting the management and conservation of Illinois aquatic resources, this research has made important contributions to the field of fisheries as a whole by providing tests of previously proposed hypotheses and developing innovative approaches to the study of fish ecology and management.

Looking to the future, it is likely that many new challenges await the field of fisheries science. Human impacts on fishery resources will likely continue to grow through influences such as global warming and movement of species. The importance of fish as a protein source for human consumption suggests aquaculture will continue as a vector for species introductions. The implications of these stock transfers on genetic integrity and the effects of invasive species on ecosystems will continue to be major issues. The aging and life expectancy of many of our lakes and associated problems from sedimentation have implications for our water supplies and fish populations, which will require new paradigms to address. Recent technological developments such as improved sampling methods, genetic markers, otolith techniques, and physiological measurements should allow greater insight at the individual, population, community, and ecosystem levels. The dramatic changes to aquatic communities combined with intensive land use and human transformation of natural systems makes continued research on the effects of changes in fish biodiversity and their effects on ecosystem function essential. The detailed historic records provided by past and ongoing INHS studies will be an invaluable resource to continue to monitor the effects of anthropogenic disturbances on long-term trends in fish community composition and structure. Since Forbes published *The Lake as a Microcosm* in 1887, we have also come to appreciate the interconnectedness of aquatic and terrestrial ecosystems, highlighting the need for additional interdisciplinary work. Current and future researchers will hopefully continue to use both old and new technologies and approaches to provide valuable information about fisheries and aquatic resources that can be used to guide future growth and sustainability.

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CHAPTER 12

Non-native and Invasive Species in Illinois

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OBJECTIVES

One of the most dramatic changes that has occurred in Illinois since Euro-American settlement is in the size of its non-native flora and fauna. This chapter will focus on exceptionally invasive species in Illinois' terrestrial, aquatic, and agricultural landscapes and habitats and will introduce some programs designed to manage invasive non-native species. Distinctions will be made between invasive and currently non-invasive species. Characteristics of successful invaders also are discussed.

INTRODUCTION

Human exploration, colonization, and commerce have led to the redistribution of plants, animals, and microbes around the globe. This movement has resulted in a world where local biotas now include a mixture of native and non-native species (1, 2). A variety of terms have been used to characterize non-native species including non-indigenous, exotic, adventive, introduced, and alien. These terms all refer to species occurring outside their natural geographic ranges. Consequently, geographic and temporal contexts are needed when applying terms such as non-native. For example, White Spruce (*Picea glauca*) is native to North America, and following the last glacial period was widespread in the region that became Illinois (3); however, its natural range retreated northward following post-glacial warming and it no longer occurs as a native species in Illinois. White Pine (*Pinus strobus*) does occur as a native species in northern Illinois; however, naturalized escapees from downstate plantings would be considered non-native. The Colorado Potato Beetle (*Leptinotarsa decimlineata*) is a native of the southwestern United States that has spread across the continent on non-native host plants (e.g., potatoes, tomatoes, eggplants, and peppers), becoming an invasive agricultural pest in the eastern states. Purple Loosestrife (*Lythrum salicaria*) and Garlic Mustard (*Alliaria petiolata*) are native to Europe and Asia; they are not only alien in North America but they also have become highly invasive species in natural communities. Invasive species are organisms (e.g., fungi, plants, animals) that can or likely will cause economic or environmental harm. The term typically is applied to non-native species and while native examples also can be found, this chapter will focus on non-native invasive species. All of the above examples can be considered non-native species in Illinois, but they differ in geographic contexts and degrees of invasiveness.

The majority of non-native plants and animals have not become problematic invasive species and many provide important economic benefits. For example, the major agricultural crops grown in Illinois are all non-native and non-invasive. Soybeans came from Asia, corn is derived from a grass native to Mexico, and wheat, oats, and alfalfa are derived from plants originating in the steppes of Asia. Most of our vegetables and fruit trees are non-native. The honeybees that pollinate the majority of these crops also are non-native.

In contrast to the economically important species listed above, there are numerous cases of non-native species that have become invasive in natural habitats such as forests, prairies, wetlands, rivers, and lakes (4), posing some of the most formidable challenges to maintaining native biodiversity. The number of non-native plants and animals is too extensive to list comprehensively here; consequently, emphasis in this chapter will be placed on selected characteristic invasive species in Illinois forest, prairie, wetland, and aquatic habitats and agricultural landscapes. Examples include Amur Honeysuckle, Autumn Olive, Kudzu, Garlic Mustard, Zebra Mussel, Bighead Carp, Round Goby, Soybean Aphid, Emerald Ash Borer, and Asian Tiger Mosquito.

One explanation for the success of these invasive species is the absence of natural enemies such as, for plants, herbivorous insects. However, escape from natural enemies does not fully explain why some species become invasive and others do not. Therefore, invasive organisms often have other characteristics that help make them successful in new regions and habitats (see Table 12.1 for botanical examples). Shared traits for many invasive species include rapid growth and reproduction, good dispersal ability, the ability to live in a wide variety of different habitats, a high level of genetic plasticity, and in some cases asexual reproduction. Sometimes these invasive species can even alter their habitats, making them less suitable for competing species. For example, the invasive Spotted Knapweed produces chemicals that are harmful to the roots of many grasses and forbs (known as allelopathy) native to North America (5), giving the species a selective advantage not found in its native habitat where associate species have adapted tolerance to this chemistry.

Table 12.1. Characteristics of an ideal weed. Many introduced exotic species have characteristics that allow them to become weedy. Though no particular species will have all of these characteristics, most have more than many of our native inhabitants, and will out compete our native species for space and resources. Data from Stuckey and Barkley (6), Baker (78), and Bazzaz (79).

1. Short life cycle
2. Seeds germinate under many different environmental conditions
3. Internal control allows for seed germination throughout year
4. Seeds remain viable for many years in the seed bank
5. Rapid growth through the vegetative phase to flowering
6. Continuous seed production throughout most of the growing season
7. Ability to self-fertilize, reproduce asexually
8. Cross-pollinated, uses unspecialized visitors or wind borne pollen
9. Very high seed output in favorable environmental circumstances
10. Production of some seed in a wide range of environmental conditions
11. Adaptations for short- and long-range dispersal
12. Vigorous vegetative propagation or regeneration from fragment if a perennial
13. Ability to compete interspecifically by special means (rosette, choking growth, allelopathy)
14. Ability to rapidly use available environmental resources
15. High degree of flexibility that can generate appropriate body form or ecology in different environments

HOW DID THEY GET HERE?

Initially, species are moved from one location to another primarily through the actions of humans. For example, it is estimated that nearly one-third of the vascular flora of most midwestern states is not native to the region, having been introduced from many parts of the world for horticultural, agricultural, and forestry purposes (6). Of 235 species of cultivated woody plants that have become naturalized in the United States, 82% were introduced for horticultural purposes (7). Many herbaceous exotics were brought to the U.S. accidentally as contaminants in crop seeds. Others arrived as seeds in soil brought from Europe as ship ballast that was dumped along port shores to accommodate cargo (8). Many non-native shrubs occurring in Illinois originally were introduced to provide food and cover for wildlife, often with the recommendation of government agencies. Grown in state-run nurseries (9), these shrubs were sold each year at relatively low prices. Some species also were advertised to control erosion, to provide living fences for livestock, or hedges in residential areas. With the development of the interstate highway system, some of these introduced non-natives were used for landscaping, as crash barriers, and to reduce headlight glare in the median of these highways. Several of these introduced shrubs currently are among the most serious threats to natural communities in Illinois (10).

Along with plants that were brought to North America, many non-native insect species living on these plants or in their soil such as scales, mealybugs, aphids, jumping plant lice, leaf feeding moths, and beetles also were introduced. Despite increasingly stringent regulations on the importation and movement of biological material, there remain several pathways by which non-native insects can make their way to North America. For example, the Asian Long-horned Beetle (*Anoplophora glabripennis*) and the Emerald Ash Borer (*Agrilus planipennis*), both discussed later in this chapter, are believed to have arrived as larvae in wood pallets used internationally to facilitate the movement of goods. Unless the pallets are treated prior to shipping (11), the probability of continuous introductions of tree/wood pests seems almost certain. An examination of one group of tree infesting beetles (the bark beetle family Scolytidae) intercepted at ports of entry from 1985 to 2000 found 67 species, many of which could become major pests if they became established. Of all the individuals intercepted, 73% were associated with solid wood packing materials (12). Container shipping is another way exotic insects make it into North America. Although the time in transit is most often days or weeks, many organisms could be carried in these containers, of which only about 5% are inspected upon arrival before moving from a port to their final destination.

Shipping activities also have been associated with the introduction of non-native aquatic organisms. Of the 189 non-native species in the Great Lakes basin, 65% are believed to have been introduced via ballast water released from ocean-going vessels (13). These species include the Round Goby (*Apollonia melanostomus*) and the Zebra Mussel (*Dreissena* spp.) (see Chapter 10). The Round Goby has since swum downstream in the Illinois River, and the Zebra Mussel has been carried by water currents and recreational water users to other waterways across the United States. Other shipping activities, such as the building of canals, also have contributed to the introduction and spread of non-natives. For example, the Sea Lamprey (*Petromyzon marinus*) swam into the upper Great Lakes via the Welland Canal, which allowed ships to bypass Niagara Falls.

Aquaculture, both pond-based and *in situ*, has also contributed to the introduction of non-natives. In the 1870s, the U.S. Fish Commission (the precursor to the U.S. Fish and Wildlife Service) widely stocked Common Carp (*Cyprinus carpio*) as food fish in lakes and streams of the U.S. (14), including those in Illinois, and it is now a common and widespread species. The Bighead Carp (*Hypophthalmichthys nobilis*) and Silver Carp (*H. molitrix*) are now firmly established in the Mississippi and Illinois rivers largely as a result of aquaculture; these planktivorous fishes are used to help control plankton in aquaculture ponds (see Chapter 9). In the early 1980s, these fish began appearing in the wild, most likely as escapees from aquaculture ponds in Arkansas. They have since spread upstream within the Mississippi and Illinois River basins (Fig. 12.1) and threaten the Great Lakes (15).

Through the intentional release or unintentional escape of pets and other aquatic species, aquarium hobbyists also have been responsible for several introductions of non-native plants and animals to Illinois (see Chapter 9). Examples include Dotted Duckweed (*Landoltia punctata*), Brazilian Elodea (*Egeria densa*), Chinese Mystery Snail (*Bellamya chinensismalleata*), Goldfish (*Carassius auratus*), Rio Grande Cichid (*Cichlasoma cyanoguttatum*), Oriental Weatherfish (*Misgurnus anguilliaudatus*), Red-Bellied Pacu (*Piaractus brachypomus*), Piranha (*Pyocentrus* or *Serrasalmus* sp.), and Northern Snakehead (*Channa argus*). Although most of these species have not become established, let alone invasive, there is still concern regarding the aquarium trade as a pathway for introducing non-native species. The Northern Snakehead (Fig. 12.2), an aggressive predatory fish from China that will feed on fish, amphibians, and aquatic birds, has been banned in Illinois because of the risk it poses to native fisheries. When one Snakehead was caught in Burnham Harbor (Chicago) in 2004, considerable effort was expended to ensure that no other individuals were present in the harbor.

Figure 12.1. A boatload of Bighead Carp on the Illinois River. Photo courtesy of D. Zalaznik ©.

Figure 12.2. Two Northern Snakeheads caught by electro-fishing in Dogue Creek, a Potomac River tributary, downstream of Washington, D.C. Photo by M. Fisher.

In Illinois, water gardens are viewed as an emerging invasion "front" because 1) water gardens are the fastest-growing segment of the nursery trade, 2) accounts of water garden "escapees" are increasingly common, and 3) there is great public demand for attractive and unusual plants to use in water gardens. Already there have been collections in natural aquatic habitats in Illinois of "typical" water garden plants (Fig. 12.3) including Yellow Flag (*Iris pseudocorus*), Water Hyacinth (*Eichhornia crassipes*), Yellow Floating Heart (*Nymphoides peltata*), and Brazilian Elodea. These and other water garden plants can enter natural water bodies when water gardens overflow or when individuals dispose of water garden species into natural waterways (16).

The sale and transfer of fishing bait also has contributed to the invasive species problem in Illinois. A prime example is the Rusty Crayfish (*Oronectes rusticus*), a species discussed in Chapter 10. This highly aggressive species first appeared in Illinois in scattered locations used for fishing and has now spread across the northern half of the state.

INVADERS OF ILLINOIS

BOTANICAL INTERLOPERS

Of the approximately 3,134 species of vascular plants recorded from Illinois, 969 (31%) are non-native species

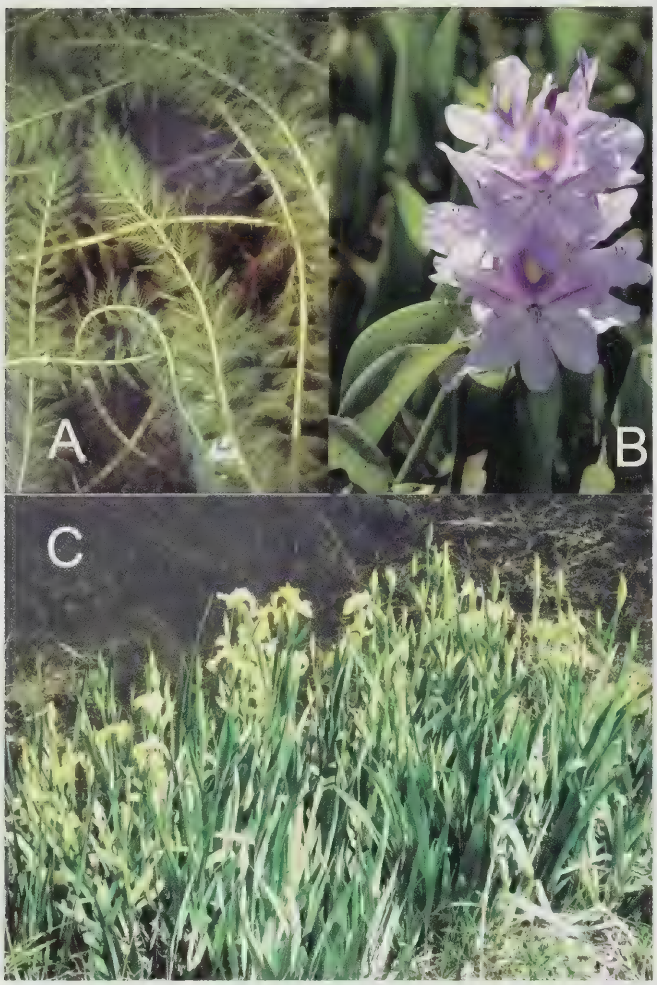

Figure 12.3. Three exotic plants used in water gardens that have escaped into Illinois wetlands and aquatic habitats: A) Eurasian Watermilfoil (*Myriophyllum spicatum*), photo by A. Fox; B) Water Hyacinth (*Eichhornia crassipes*), photo by W. VanDyk Evans; and C) Yellowflag Iris (*Iris pseudoacorus*), photo by L. Mehrhoff; Bugwood.org.

(17). While most of these have not (yet) become problematic invasive species, there are numerous exceptions that threaten the integrity of native habitats including forests, prairies, and wetlands.

Forest Habitats—Some of the most invasive non-native species in the Midwest occur in forest habitats (18). Non-native species in forests include trees, shrubs, woody vines, and herbaceous ground layer species. Some exotic trees are locally common in urban forests such as Tree-of-Heaven (*Ailanthus altissimus*), White Poplar (*Populus alba*), and Golden Raintree (*Koelreuteria paniculata*) while others are more widespread including White Mulberry (*Morus alba*), Osage Orange (*Maclura pomifera*), and Black Locust (*Robinia pseudoacacia*), a species considered native in Illinois, but only in counties bordering the Ohio River. However, even species originally limited to urban areas have now been found in nonurban forests.

White Mulberry is an interesting example because it first was introduced along the Atlantic seaboard during colonial times in an attempt to establish a silkworm industry (19). Transported west by early settlers, White Mulberry is now common throughout the eastern U.S., including Illinois where it is found primarily in disturbed forests, fence rows, and abandoned fields. Osage Orange (Fig. 12.4) was introduced from its native range in the southern Great Plaines to Illinois as a living hedge but has become widely established in formerly pastured riparian forests (see SIDEBAR – Osage Orange). A couple of newly emerging invasive tree species include Amur Maple (*Acer ginnala*) and the Callery Pear (*Pyrus calleryana*). While both are only locally abundant, they appear to have the potential to expand, particularly in forest edge habitat (26, 27).

Some of the most invasive forest species are shrubs (Figs. 12.5A–F) including Common Buckthorn (*Rhamnus cathartica*), Glossy Buckthorn (*Frangula alnus*), several species of bush honeysuckle (*Lonicera* spp.), High-Bush Cranberry (*Viburnum opulus*), Winged Wahoo (*Euonymus alatus*), and Multiflora Rose (*Rosa multiflora*). These and other invaders have had substantial human assistance, not only with intentional introduction but in becoming so successful. The following invasive shrubs are examples of species that owe part of their successful spread into native midwestern habitats to human assistance, through intensive programs of breeding, marketing, and landscaping.

Multiflora Rose (*Rosa multiflora*)—Many of our ornamental shrubs become established in the wild and compete with native species. Some exotic shrubs, however, are even more insidious. They do more than take-up space - they make the space nearly impenetrable for all but small animals. An "old-timer" of this group is Multiflora Rose (Fig. 12.5A). Originally introduced into the United States from Japan in 1866, this species was used as an understock for ornamental roses. However, beginning in the late 1930s the United States Soil Conservation Service praised the many "virtues" of this thorny shrub (9) and advocated its extensive use for wildlife cover and food, soil erosion projects, and as a living fence to confine livestock. With such promotion, Multiflora Rose has transformed itself into a serious invader of pastures, old fields, prairies, savannas, open woodlands, forest edges, and even mature forest interior zones near tree-fall gaps. Because it is avoided by grazing animals, Multiflora Rose is a classic grazing increaser, becoming abundant in many habitats, particularly forests and woodlands with a history of livestock grazing (28, 29).

Winged Wahoo (*Euonymus alatus*)—Another emerging invasive shrub species is Winged Wahoo or Burning Bush (Fig. 12.5B). This species, a native of eastern Asia, is a common ornamental that recently has been used extensively in landscaping along interstate highways. Its form and bright crimson autumn foliage make it a desirable shrub. Unlike Autumn Olive (*Elaeagnus umbellata*), which in mature forests is usually limited to tree-fall gaps, Winged Wahoo survives in the dense shade of closed canopy forests, and has appeared in some Illinois nature preserves (33). Many species of shrubs continue to be introduced for ornamental purpose because nurseries are continually looking for something new and different with commercial appeal.

Osage Orange—"Horse-high, bull-strong, and pig-tight"—During the early and mid 1800s Illinois was open range. It was not until 1854, when the railroads were well established, that fencing laws were enacted. Many a debate arose on whether the farmer who grew the crop or the livestock owner should erect the fence. For either party it was an expensive venture. Upon buying his land, a farmer would have to pay 16 to 24 times the original purchase price per acre to erect a wooden fence. In 1847, Professor Johnathan Turner introduced Osage Orange (*Maclura pomifera*) into Illinois to use as a living fence (20). This thorny tree native to southern Arkansas, Oklahoma, and adjacent Texas, with its characteristic knobby green fruits (Fig. 12.4), made an excellent living fence. Easily split and slow to decay in the ground, it also makes excellent fence posts. By the late 1800s, a survey in Iowa indicated that 39% of all fences were of Osage Orange; in Kansas this figure was close to 60%; while in Kankakee County, Illinois Osage Orange accounted for nearly 75% of all fencing (21). Osage Orange fit all the requirements of the settlers for fencing. It was cheap, grew fast, was easily started, could survive the climate of the prairie, was armed with stout thorns, was not harmed by animals or insects, and produced a tight hedge (22). It was advertised as being "horse-high, bull-strong, and pig-tight" (23). The coming of barbed wire meant the gradual grubbing out of the many miles of Osage Orange hedge, a progress that is still continuing today (24). Presently, Osage Orange grows throughout Illinois in hedgerows, pastures, riverbanks, and often in formerly pastured forests (24, 25).

Figure 12.4. Osage Orange (*Maclura pomifera*), a member of the Mulberry Family, with large, aggregate fruit (inset). Photos by J. Taft

Figure 12.5. Invasive shrubs that infest Illinois forest habitats including A) Multiflora Rosa (*Rosa multiflora*) with diagnostic fringed stipules and fruits (inset), B) Winged Wahoo (*Euonymus alatus*), C) Amur Honeysuckle (*Lonicera maackii*), D) Glossy Buckthorn (*Frangula alnus*), E) High-Bush Cranberry (*Viburnum opulus*), and F) Common Buckthorn (*Rhamnus cathartica*). Photos by J. Taft.

Amur Honeysuckle (*Lonicera maackii*)—Native to eastern Asia, Amur Honeysuckle (Fig. 12.5C) has been a commonly used ornamental shrub since its introduction into North America in 1898 (30). The tendency of Amur Honeysuckle to spread beyond the original plantings was first recognized in the mid-1920s, and naturalized individuals were being reported in the 1950s. Nevertheless, from the 1960s to 1984, the U.S. Department of Agriculture (USDA) Soil Conservation Service sponsored a program to develop "improved" cultivars that provided cover and food for wildlife, stabilized and reclaimed soil, and improved ornamental quality. Since that time this species has spread into many habitats in Illinois, including closed canopy forests. In the spring, it is one of the earliest shrubs to have leaves; in the fall it holds its leaves much later than its community associates. Thus, this species like many other invasive plants has a longer growing season that provides a competitive advantage.

Autumn Olive (*Elaeagnus umbellata*)—A relatively recent introduction, this species of eastern Asia is now found throughout much of the northeastern U.S. The USDA Soil Conservation Service started studying this species in 1940, and the strain "Cardinal" was released in 1963 for commercial production (31). By 1982, the Illinois Department of Conservation was distributing more than 1 million autumn olive seedlings a year, representing about 20 percent of the entire state's nursery production (9). Though not originally considered to spread extensively from cultivation (32), it was

Figure 12.6. A) Dense thicket of Amur Honeysuckle (*Lonicera maackii*) and Multiflora Rosa (*Rosa multiflora*) and B) shaded ground layer devoid of forest ground layer herbs. Photos by J. Taft.

Figure 12.7. Japanese Honeysuckle (*Lonicera japonica*) vines along a wire fence. Photo by C. Bryson, Bugwood.org.

soon found as seedlings and small individuals around original plantings (33, 34). This species is now common throughout most of Illinois, going from an unknown in 1963 to our most abundant widespread exotic shrub in disturbed habitats (35). The state nurseries of Illinois are no longer growing this species, but it can still be found in commercial nurseries, and is still used for landscaping.

The above mentioned species can become so abundant that they profoundly shade the ground layer often resulting in little or no herbaceous growth (Figure 12.6). Expansion of Common and Glossy buckthorn and perhaps others owe some of their success to complex interactions with other species (see section on Interactions among Invader Complexes). While humans assisted these species in introduction and initial spread, all these shrubs are bird dispersed making elimination and control very challenging, if not impossible.

Invasive non-native woody vines not only can infest forests, but their sprawling growth can overwhelm a site, producing enough biomass and shade to lead to tree mortality and a sparse understory. Japanese Honeysuckle (*Lonicera japonica*) may have been the earliest of these to invade Illinois forests (Fig. 12.7). This vine was introduced into the U.S. from eastern Asia as an ornamental. Since the early 1920s, it has been widely planted as a source of food and wildlife cover (10, 36). This species has become a major threat to forest and edge habitats and the organisms that occur in them, especially in the southern half of Illinois. An aggressive colonizer, this vine can climb and drape over native vegetation, completely cover understory plants, and ascend into the forest canopy. This vine grows rapidly and its semi-evergreen habit allows for growth throughout much of the year (37). A more recent Asian invader that grows in this same way is Kudzu (*Pueraria lobata*). Kudzu is common in the southeastern U.S. and is moving north (38). Twenty-five years ago it was known from a single location in Illinois. A survey in 2003, however, found it in over 30 counties with one population as far north as Rock Island in northwestern Illinois (39). Kudzu is a close relative of the soybean, and is an alternate host of the recently introduced Soybean Rust. Chinese Yam (*Dioscorea oppositifolia*) is a newly emerging invasive herbaceous vine with many populations discovered along riparian corridors throughout the Shawnee National Forest (40). Growth of this vine begins in April; by the end of the growing season an individual commonly exceeds 4 m in length, blanketing nearby vegetation. Though seeds are sometimes produced, reproduction is mostly asexual; the plant produces small potatolike bulbils within its leaf axils that are 1–2 cm in diameter. The bulbils remain dormant throughout winter, then root and establish a new plant the following spring. Chinese Yam could become a major plant pest in the southern half of Illinois and spread throughout the state.

Perhaps the most serious invasive species problem in forests is the threat that herbaceous exotics pose to the forest ground layer, where the majority of native plant diversity resides. Chief among those threatening the ground layer, is the annual/biennial herb Garlic Mustard. This species is now common throughout most of the north-central and northeastern U.S. and parts of Canada (41). Imported

from Eurasia as a food and medicinal herb, this species was first collected in Illinois in 1918 north of Chicago; by 1991 it had spread to 42 counties in northern and central Illinois and two counties in southern Illinois (42). A prodigious seed producer, Garlic Mustard is becoming a major threat to the herbaceous woodland flora of northeastern North America, and to the wildlife that depend on native species for food and cover (43). Part of its success appears to be related to toxic (allelopathic) effects its populations have on beneficial soil fungi (mycorrhizae) that interact with native herbs (44) and trees (45). Seed dispersal is by wildlife, gravity, floodwaters, and anthropogenic means (e.g., vehicles distribute seeds along road corridors). In particular, deer and other animals that move within and between sites apparently serve as primary seed vectors to isolated areas (42). Natal Grass (*Microstegium vimineum*), another problem exotic that is most common in southern Illinois forests, may eventually rival Garlic Mustard as a major pest throughout Illinois forests.

Prairie Habitats—The small size and isolated circumstance of many remaining prairies in Illinois (see Chapter 4) makes them especially prone to invasion by non-native species. Many of the pioneer cemetery prairies have been planted with numerous non-natives and have become microcosms of exotic species problems, with so many at some sites that management conflicts can emerge. For example, an effective treatment for one non-native may lead to increases for others. Perhaps the most ubiquitous non-native plant in the tallgrass prairies of Illinois is Kentucky Bluegrass (*Poa pratensis*), a short cool-season species from Eurasia (not Kentucky!). It is widespread and common in many prairie remnants, often ranking among the most abundant species. An example of a management conflict comes from timing of prescribed burns. One strategy for controlling Orange Day Lily (*Hemerocallis fulva*), a non-native species that has spread like a cancer at some sites, is to burn very early in the spring (during the plant's dormant cycle) to remove litter and duff on the soil surface. This promotes early greening of Day Lily for targeted herbicide control. However, by burning early, Kentucky Bluegrass, also unharmed by fire when dormant, is given a selective advantage with an early head start over many native species by the reduced competition when litter and duff are removed. Other non-native species common to Illinois prairies include Yellow and White Sweet Clover (*Melilotus* spp.), Wild Parsnip (*Pastinaca satica*), Cemetery Spurge (*Euphorbia cyparissius*), Smooth Brome (*Bromus inermis*), Wild Carrot (*Daucus carota*), Common Periwinkle (*Vinca minor*), Fescue (*Festuca pratense*), and Wild Asparagus (*Asparagus officinale*).

Wetlands—While there are only about 90 non-native wetland plant species in the Illinois flora (see Chapter 5), some of these are highly invasive. One of these is Purple Loosestrife (*Lythrum salicaria*), a species native to wetlands in Europe (46), brought to North America in the early 1800s by European settlers for their flower gardens and as seeds in soil used for ship ballast. However, it is such an aggressive invader of North American emergent wetland habitats (e.g.,

Figure 12.8. Purple Loosestrife (*Lythrum salicaria*) dominating an Illinois marsh in Lake County. Photos by J. Taft.

Biological Control of Purple Loosestrife—Stands of Purple Loosestrife have become so large they defy traditional control measures (e.g., hand pulling, burning, herbicides). Consequently, efforts to control Purple Loosestrife biologically have been studied because evidence suggested that part of the success of Purple Loosestrife in North America may have been related to its escape from natural predators in its native European ecosystem (80). Biological control involves growing, releasing, and establishing populations of an organism's natural enemies. In this case, enemies of Purple Loosestrife include two species of chrysomellid beetles from Europe (*Galerucella calmariensis* and *G. pusillus*) (SIDEBAR FIG. 1). Protocols for rearing and releasing *Galerucella* beetles have been established and over 2 million beetles have been release at 210 Illinois sites. Over 250 educators have been trained for Purple Loosestrife biological control efforts and have incorporated a curriculum that includes rearing these beetles in their classrooms and releasing them into local wetlands. Monitored results indicate that Purple Loosestrife is declining in Illinois and native plants are beginning to recover (47). Careful observations in Illinois, as well as in other states where these beetles have become established, have not documented any significant impact of these non-natives on any native vegetation (41).

Sidebar Figure 1. Leaf feeding chrysomellid beetles (*Galerucella* sp.) on Purple Loosestrife: A) larvae feeding on upper surface of leaf and B) adult female laying eggs. Photos by D. Voegtlin.

Fig. 12.8) that it now infests wetlands in most of the 50 states (46). In Illinois, it has invaded emergent wetlands throughout the state and can often be found along many roadside ditches. This perennial grows to 2–3 m (~ 6–10 ft) in height, and can form dense stands that exclude other plants, including native species that provide food and habitat for wildlife. There are promising results from experimental efforts at biological control to limit the abundance of Purple Loosestrife in Illinois wetlands (see SIDEBAR—Biological Control of Purple Loosestrife). Other major invasive species of wetland habitats include Reed Canary Grass (*Phalaris arundinacea*), a species that has been widely planted for erosion control, Common Reed (*Phragmites australis*), and Narrow-Leaved Cattail (*Typha angustifolia*). Many wetlands in Illinois, particularly those in agricultural or developed landscapes, are strongly dominated by just these species.

ANIMAL INTERLOPERS

Non-native animals invading Illinois agricultural areas and natural communities that receive the greatest notoriety include arthropods, particularly in agricultural systems, and a host of invertebrate and vertebrate groups found in aquatic habitats. Introduced mammals and birds are addressed in Chapter 6, with the exception of feral hogs, singled out here because they are a newly emerging non-native speices problem with the capacity for tremendous habitat damage. Free-roaming or feral hogs were first reported in extreme southern Illinois in 1993 and are known to occur in eight additional counties in that region. These hogs compete with other native species for food resources and damage native vegetation. For additional information on feral hogs and the damage they have caused in Illinois readers are referred to McClain and Esker (48).

Non-native Arthropods—Insects are the most diverse group of organisms and there are a great many non-native species in Illinois. A few taxa that have earned some notoriety are described in this section to provide examples of the kind of havoc that can be caused by even the most diminutive invaders.

About 7% of the aphid species found in Illinois are non-native, including some efficient vectors of plant viruses such as the Green Peach Aphid (*Myzus persicae*) and the Cotton Melon Aphid (*Aphis gossypii*). Most of these species are cosmopolitan in distribution and have a very broad host range. In the case of aphids, all introductions have been accidental and in most cases there is no information on how these species arrived in North America. A relatively recent accidental aphid introduction has cost Illinois and other midwestern farmers millions of dollars. The Soybean Aphid destroys soybeans by direct consumption of sap and/or transmission of viral diseases. Female Soybean Aphids will deposit live young under soybean leaves in the spring and will continue to lay up to 15 generations through the summer months. In 2003, an outbreak of the Soybean Aphid (see SIDEBAR—The Good, the Bad, and the Stinky) occurred across the Midwest. In Illinois, an estimated 10–15% reduction in the soybean crop was attributed to the impact of large populations of this aphid. That year approximately

The good, the bad, and the stinky—Soybeans first were introduced to Illinois in 1851 and in the following few years were grown and distributed to many farmers. For approximately the next 150 years, cultivation of this important crop was pretty much without worry of crop loss to insect pests. This changed dramatically in the year 2000 when the Soybean Aphid (*Aphis glycines*), native to China, was discovered in northern Illinois and southern Wisconsin (SIDEBAR FIG. 2A). This aphid rapidly spread into adjacent states and within a couple of years was found in most of the major soybean growing areas of North America. A study of its biology discovered that the aphid survived the winter as eggs on Common Buckthorn (*Rhamnus cathartica*) (Fig. 12.5F), another non-native species of European origin. In years of high aphid numbers in soybeans, the most common natural enemy of the aphid is the non-native Multi-colored Asian Lady Beetle (*Harmonia axyridis*) (SIDEBAR FIG. 2B). With a virtually unlimited supply of soybean aphids on which to feed, by the end of the growing season uncountable numbers of this lady beetle are produced. In late October, these lady beetles aggregate on buildings and crawl into cracks and crevices looking for a place to overwinter. Many find their way into houses where they can become a nuisance. People that handle the Multi-colored Asian Lady Beetle soon discover that they defend themselves by exuding a foul-smelling yellow-orange body fluid, which is their blood. Besides being foul smelling the blood can permanently stain walls, drapes, and carpeting. A completely exotic system, therefore, is established and functioning in North America: the good soybean, the bad aphid and bad buckthorn, along with the stinky lady beetle that is beneficial by feeding on a pest aphid, but also can itself become a pest.

Sidebar Figure 2. Examples of non-native insects in Illinois involved in multiple species interactions: A) Soybean Aphids (*Aphis glycines*) and B) Multi-colored Asian Lady Beetle (*Harmonia axyridis*). Photos by D. Voegtlin.

11 million acres of soybeans were planted in the state. A 10% loss is the equivalent of not planting 1.1 million acres of soybeans, resulting in loss of income to Illinois farmers of approximately $200 million. Entomologists have developed a reliable economic threshold that can be used to make control decisions for this aphid, allowing farmers to limit populations of the aphid with insecticides before they reach damaging levels (49). In outbreak years, costs to the farmers are now primarily from control measures rather than lost production and these control measures, collectively, can cost Illinois farmers millions of dollars.

The Emerald Ash Borer (*Agrilus planipennis*), first found in Illinois in 2006, demonstrates the potential landscape impact a non-native insect can have. It was first discovered in North America near Detroit, Michigan, in 2002 and has since spread into Indiana, Illinois, Ohio, Pennsylvania and Ontario, Canada. In a recent summary of the Emerald Ash Borer invasion, Poland (50) states that the infested area is now greater than 40,000 square miles and an estimated 20 million ash trees have been killed in the core infested area. These quarter-inch-long, bright-green beetles (Fig. 12.9) live only in ash trees (*Fraxinus* spp.), which are widespread in many forest types and widely planted in urban areas. The result of this accidental introduction is major forest habitat modification through the removal of all ash trees. Ashes comprise just over 19% of the street trees in Chicago and approximately 6% of our forest trees in Illinois (51) It is difficult to monitor the spread of the Emerald Ash Borer as the adults are not known to respond to attractants. Newly attacked trees cannot easily be detected because females lay eggs in bark crevices, and the tiny larvae burrow through the outer bark into the inner bark (i.e., the phloem).

Infested trees may not be detected until either adult beetles emerge, leaving a signature D-shaped opening or the tree begins to show signs of the beetle's impact. In either scenario, it is usually too late to save the tree. Removal of all ashes around infested sites is done to limit spread, a control strategy that can be very expensive. At present there seems to be no alternative, cost-effective method to prevent the gradual spread of this beetle across the landscape and thus the potential decline of ash trees. In July 2007, 18 counties in northeast Illinois were quarantined, which made movement of firewood and yard wastes from these infested areas illegal. Approval is being sought for the release of two parasitic wasps, natural enemies of this beetle, into North America (52). Hopefully these wasps from China will help limit the spread and impact of the Emerald Ash Borer in North America.

The tremendous financial costs of invasive insects can be illustrated by what has happened with the Asian Longhorned Beetle (ALB) (*Anoplophora glabripennis*). First discovered in New York in 1996 and then in Chicago in 1998, the ALB attacks healthy maples, elms, willows, poplars, and birches by boring directly into the tree. Eggs are laid along the hole that is bored, and the resulting larvae then bore into the main part of the tree. In Chicago, the infested region was immediately quarantined and infested trees were cut down and chipped on site to prevent the distribution of the beetle in infested logs. The last infestation in Chicago was found in 2003, but intensive surveys continued through 2006. The cost of removing and chipping over 1,500 trees in Chicago and approximately 5,000 trees in New York was over $25 million (53). Replacing the trees, education and outreach, insecticidal treatment of trees at risk, and continued surveys added more millions of dollars to the cost. Although Chicago has been declared beetle-free as of 2006, the ALB is still found in New York. The USDA Animal and Plant Health Inspection Service (APHIS) estimates that $48 million per year through 2014 would be needed to eradicate the ALB in the New York area. These figures pale in comparison to the potential cost of an unchecked ALB in North America. Nowak et al. (53) examined the tree composition of cities in the U.S. and estimated that cost per city in lost trees would range from $72 million to $2.3 billion. The number of suitable hosts in urban areas in the U.S. was estimated at 1.2 billion trees. This excludes the ecological cost resulting from the loss of susceptible trees in forests and woodlands across the country. Maximum possible effort can clearly be justified to eradicate this beetle from North America, and to reduce the possibility of another accidental introduction.

In addition to impacts on the flora and fauna of North America, some non-natives such as mosquitoes have a direct impact on human populations. The Asian Tiger Mosquito (*Aedes albopictus*) is one such organism (Fig. 12.10), and was first found in the U.S. in 1985. Because

Figure 12.9. Emerald Ash Borer (*Agrilus planipennis*) adult. These non-native insects infest and can kill native ash trees (*Fraxinus* spp.). Photo by D. Cappaert, Bugwood.org.

Figure 12.10. Asian Tiger Mosquito (*Aedes albopictus*) showing distinct coloration. Photo by S. Ellis, Bugwood.org.

it will lay its eggs and the larvae will develop in any small container that is holding water, it is called a container mosquito. Thus, the accumulation of huge used-tire piles where rain collects has provided ideal habitat for the production of this mosquito. In Illinois, the Asian Tiger Mosquito can be an annoying daytime biting pest, but is also a vector of LaCross Encephalitis. Diseases that both native and non-native mosquitoes transmit can create major concerns for public health. West Nile Virus was first discovered in Illinois in late 2001; by 2006, a total of 1,465 human cases and 94 deaths attributed to this disease were recorded in the state. This virus has been detected in over 60 species of mosquitoes, including both natives and non-natives. The most common vector in Illinois may be the non-native *Culex pipiens*. The impact of West Nile Virus extends beyond humans. Some birds such as the American Crow and Blue Jay are highly susceptible, and a significant percentage of horses infected with the virus will die if not treated.

Invaders of Aquatic Habitats—Aquatic invasive species inhabit every type of water-related habitat in Illinois including Lake Michigan, inland lakes, rivers, streams, ponds, wetlands, ditches, backyard water gardens, and even water collected in used tires. Likewise, the types of aquatic invaders in Illinois include everything from microscopic animals to robust plants (e.g., Purple Loosestrife), and fish weighing up to 60 lbs. Many of these invasive species have had or are expected to have significant impacts in Illinois. Two of the worst offenders thus far are the Zebra Mussel (*Dreissena polymorpha*) and the Quagga Mussel (*Dreissena rostriformis* ssp. *bugensis*), lumped for convenience here as Zebra Mussels. Both species are relatively small (< 4 cm in length), and are native to drainages of the Black, Caspian, and Aral seas in Eastern Europe-Western Asia. They were most likely brought to North America as larvae in ship ballast water. These ships traveled from freshwater Eurasian ports inhabited by the mussels to the Great Lakes, where the ballast water and the Zebra Mussel larvae they contained were released.

Zebra Mussel larvae (called veligers) and adults can be spread through many mechanisms including water currents, anglers' bait buckets, and boaters' bilge and live wells. Adults can also be spread when they attach to boats and aquatic plants, which are then transported to other waterways. Zebra Mussels most likely spread into Illinois via all of these mechanisms. Water currents played a particular role in that they moved veligers from Lake Michigan downstream through the Chicago waterways and into the Illinois River. Once established upstream in the Illinois, these colonies supplied veligers to downstream regions (54) and in this way came to infest the whole lower Mississippi River (Fig. 12.11).

Zebra Mussels also have spread to over 20 inland lakes in Illinois. Impacts in these inland lakes are only anecdotal, but range from no obvious effect to fouled boat hulls and dock pilings to blooms of blue-green algae; Zebra Mussels avoid blue green algae to feed preferentially on other plankton. In the Illinois River and Mississippi rivers,

Building Barriers—On the Chicago Sanitary and Ship Canal, not far from Romeoville, sits a small, white, innocuous box of a building that blends in with the industrial nature of the setting (SIDEBAR FIG. 3 and Fig. 9.13). The nearby signs warning barges not to moor are a clue to this building's purpose—that of housing the mechanics necessary for the aquatic nuisance species electrical dispersal barrier submerged below.

In 1996, the U.S. Army Corps of Engineers, with support from Congress and the State of Illinois, constructed and continues to maintain an experimental barrier with the hope of keeping aquatic species from moving between the Great Lakes and Mississippi River basins via the Chicago waterways. The Zebra Mussel had accomplished this feat in the early 1990s, which awakened biologists to the fact that other species, particularly invasives, could do likewise. In fact, in 1999 while the barrier was still being designed, another invasive species, the Round Goby made its way from Lake Michigan down the Chicago waterways and past the barrier site. An advisory group of technical experts determined that an electrical barrier would be most feasible, and the first phase of the barrier was completed and activated in 2002 (58). Larger, more powerful barriers are currently being constructed to take over when this barrier succumbs to corrosion.

The first invasive species most likely to test the barrier's effectiveness will be Bighead and Silver Carp. These fish are heading upstream in the Chicago Sanitary and Ship Canal toward the barrier and Lake Michigan; if they were to make it into Lake Michigan, they would have access to all of the other Great Lakes.

Experiments on target fish species reactions to various electrical configurations contributed significantly to the present design of the barrier (59). Scientists also have tagged and are monitoring the movements of Common Carp, using them as Bighead and Silver Carp mimics (60). This monitoring study will help anticipate the barrier's effectiveness against these invading species and prevent the movement of non-native invasive species between the Great Lakes and Mississippi River basins.

Sidebar Figure 3. This non-descript building found along the Chicago Sanitary and Ship Canal in northeastern Illinois houses the equipment necessary to maintain an electric dispersal barrier. Photo by P. Moy.

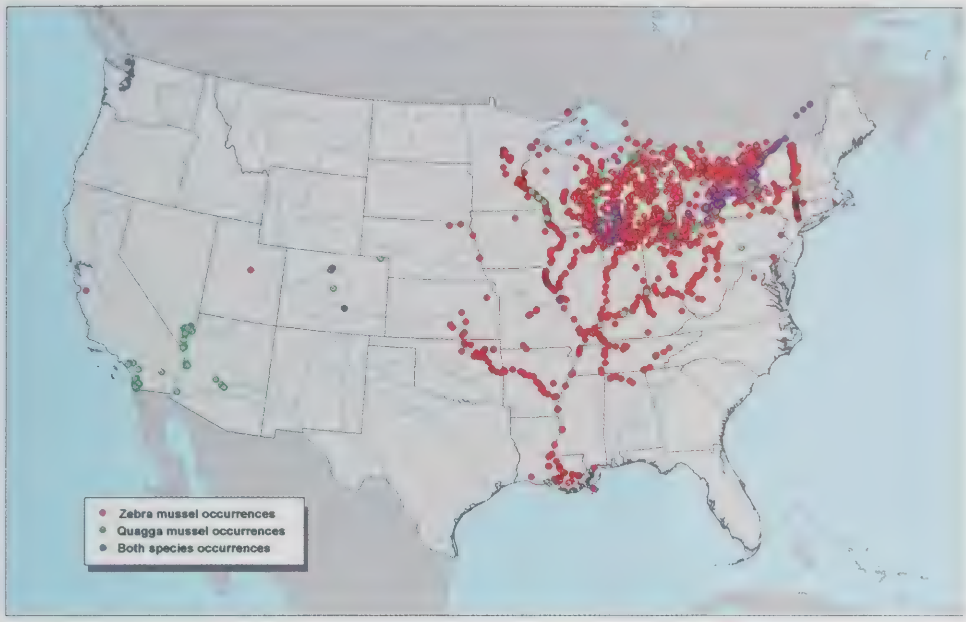

Figure 12.11. Distribution of Zebra and Quagga mussels. Map courtesy of United States Geological Survey.

native mussels have received the brunt of the Zebra Mussel invasion; numbers of native mussels declined when Zebra Mussels invaded (55, 56) because Zebra Mussels either 1) fouled the native mussels' shells (see Fig. 13 in Chapter 10), preventing them from opening and feeding, and/or 2) "cemented" the sediments found around native mussels with their byssal threads (adhesive protein filaments used for attachment). This latter action prevents the natives from burrowing to escape water fluctuations. These environmental costs are in addition to those incurred by industry in removing Zebra Mussels from water intakes, costs estimated to be about $100 million per year nationally (57).

The ecological threat posed by the movement and establishment of aquatic nuisance species such as the Round Goby, Bighead Carp, Silver Carp, and Snakehead was so great that an experimental electrical dispersal barrier has been established in the Chicago Sanitary and Ship Canal, the main channel connecting the Mississippi and Lake Michigan watersheds (see SIDEBAR—Building Barriers).

INTERACTIONS AMONG INVADER COMPLEXES

There are instances in which more than one organism invades a given area. When this occurs, there often are interesting and sometimes complex interactions among the invasive species. Take for example the case of Night Crawlers (*Lumbricus terrestris*) and Common Buckthorn (*Rhamnus cathartica*). Remarkably, the Night Crawler commonly used as bait is a native of Europe, not North America. This and other earthworms from Asia and South America have been introduced throughout the past century. These much-praised soil aerators and enrichers are coming under increased scrutiny for their exceptionally rapid recycling of the leaf litter in forests of the Midwest (61). Rapid removal of this organic layer has serious ramifications for the myriad organisms that rely on this mulch for their existence. In addition, earthworms may facilitate establishment of other non-native species. For example, Heneghan et al. (61) examined the interaction of earthworms with Common Buckthorn, one of the major invasive shrubs in the Midwest. Their studies show that earthworm populations were highest in forest patches where buckthorn was common. In turn, the forest habitats altered by earthworms facilitated invasion and survival of buckthorn. At these infested sites, leaf litter rapidly disappears by early summer leaving the soil surface bare and unsuitable habitat for the microbes, invertebrates, and vertebrates that depend on leaf litter for food. Buckthorn fruits germinate very effectively on bare mineral soil

Dramatic Changes Due to Disease—The small European Bark Beetle (*Scolytus multistriatus*), one of the vectors for the fungus that causes Dutch Elm Disease, was first discovered in the United States in 1909 and found in central Illinois in 1950. By the mid 1960s, due to Dutch Elm Disease the large stately American Elms (*Ulmus americana*) of parks, roadsides, and residential areas in Illinois were mostly dead. However, American Elm also was an important species in many of the stream-side and terrace forests in Illinois and the disease also had a major impact on the composition and structure of these forests (10).

For example, forest composition and structure have been studied for many years in Brownfield Woods, a 24-hectare remnant of a streamside prairie grove that once occupied about 2,600 hectares along the Salt Fork River northeast of Urbana, Illinois. These long-term data provide a means to track changes as a result of infection by Dutch Elm Disease. Both the American (*Ulmus americana*) and Slippery (*U. rubra*) elms were common overstory species in this forest in the early 1900s (62), exceeded in density only by Sugar Maple (*Acer saccharum*). Partly as a result of Dutch Elm Disease, American Elm was nearly eliminated from the woods by 1991 (63). Slippery Elm also had a relatively rapid decline in importance among canopy trees (63, 64, 65). Slippery Elm, though affected by phloem necrosis (an infection caused by a bacteriumlike mycoplasma) and Dutch Elm Disease, regenerated rapidly along with Sugar Maple in the openings created by the dead American Elm. However, increased shade from canopy closure in the dead-tree gaps eventually favored the more shade-tolerant Ohio Buckeye (*Aesculus glabra*) and it became a dominant species. Without stand opening disturbances and disease resistance, American Elm may never return to its former dominance in Brownfield Woods.

A similar example has been documented in another small central Illinois woodlot where the larger elms were already dead when the forest was first surveyed in 1964. Elms formerly accounted for over 50% of the overstory trees (66). When the same woodlot was again surveyed in 1983, the elms as a group had recovered to rank third in importance due to predominance in the seedling, sapling, and small tree size categories. At that time, dead elms accounted for 14% of all standing elms indicating that mortality from Dutch Elm Disease and phloem necrosis is ongoing and having a lasting impact on the forest (67).

(as does Garlic Mustard), thus a positive feedback system is created between these non-native species. Heneghan et al. (61) suggest that even after the removal of buckthorn from a site, the earthworm population will remain high and the soil may be altered to such an extent as to make restoration efforts more difficult.

Another example of multiple species interactions is Dutch Elm Disease caused by one of two closely related fungi of European origin (the most virulent being *Ophiostoma novo-ulmi*). The non-native fungus is spread by both the native Elm Bark Beetle (*Hylurgopinus rufipes*) and the European Elm Bark Beetle (*Scolytus multistriatus*), and infects native elms throughout Illinois, particularly American Elm (*Ulmus americana*). Perhaps surprisingly, due to a predominance of small trees and saplings, American Elm remains among the most common forest trees in Illinois (see Chapter 15); however, as a result of the disease, dramatic changes in the composition and structure of moist forests have occurred regionally in the state (see SIDEBAR—Dramatic Changes). American Elm used to be a very popular residential tree and it also once dominated the quad at the University of Illinois in Urbana-Champaign, but it eventually succumbed to the disease (Fig. 12.12). Root graphs between closely spaced trees can lead to rapid spread of the disease.

Multiple species interactions are well-illustrated by the changes that occurred in Lake Michigan fisheries in the 1900s. In the early 1900s, Lake Trout (*Salvelinus namaycush*) were very abundant in Lake Michigan, sustaining a robust fishery (~2,400 metric tons harvested/year). Shortly after the Sea Lamprey (*Petromyzon marinus*) made its way from the Atlantic Ocean into the lake in 1936 (Fig. 12.13), the Lake Trout population collapsed. Because their preferred prey was no longer abundant, lamprey then switched to Lake Whitefish (*Coregonus clupeaformus*), whose population collapsed shortly thereafter. The lack of large and abundant predators allowed non-native Rainbow Smelt (*Osmerus mordax*), first found in the lake in 1923, and non-native Alewife (*Alosa pseudoharengus*), to proliferate. Commercial catches of the latter (a maximum of 24,000 metric tons in 1967) hint at its huge population. With the increased population of Rainbow Smelt came a decrease in the population of native Lake Herring (*Coregonus artedi*). The increase in Alewife brought about decreases in the lake's deepwater ciscoes (Coregoninae), which were already in decline because of over fishing. In fact, several species of ciscoes have completely disappeared from the lake because of these ecosystem changes (68). In part to control the Alewife population, but also to take advantage of it, Pacific salmon (*Oncorhynchus* spp.) were stocked into the lake beginning in 1966 (about 10 years after lamprey control programs began); these salmonids continue to be stocked in the lake today, with only minimal natural reproduction occurring. It is possible that the above perturbations made it possible for the newer aquatic invasive species introductions (e.g., Round Goby) to gain a toehold in Lake Michigan, and it is undeniable that these perturbations continue to influence the function of the Lake Michigan ecosystem today.

Figure 12.12. Removal of American Elm in 1954 in front of the English building on the University of Illinois quad. Photo from the U of I Archives.

Figure 12.13. Lake Trout with two Sea Lampreys attached. Photo from U.S. Fish and Wildlife Service archives.

EVOLUTION OF INTRODUCED SPECIES

As has been shown above, there are many non-native organisms in Illinois and throughout North America. For the most part, these organisms have been treated as static identities; however, once established they can become dynamic populations with genetic diversity that has been documented using recently developed genetic tools such as DNA fingerprinting and sequencing. These tools have been useful in identifying the likely geographical origins of introduced organisms. In addition, these tools provide insights to what happens genetically to a species after it arrives in a new habitat. Many non-native species are genetically incapable of surviving in the environment into which they are introduced. For example, species incapable of surviving winter temperatures will not successfully

establish in most of the United States and Canada. Introduced species that do establish founder populations undergo immediate selective pressure from the biotic and abiotic features of their new habitat. If the number of individuals introduced is few, the genetic variability may be small and their response may be limited; however, given a low populatin size, change may occur over relatively few generations once established. Many midwestern non-natives have been repeatedly introduced, intentionally and unintentionally, in large numbers, providing the genetic diversity to survive, adapt, and expand in a new environment. Potential outcomes and interactions can be highly varied (69). Herbivores may expand their host range, hybridization may occur with closely related species, and new associations may form that can have dramatic effects such as a native bark beetle transmitting the fungus responsible for Dutch Elm Disease. Escape from predator organisms in new regions also can allow the expression of previously suppressed genetic variability among non-native species.

Purple Loosestrife, a common invasive wetland weed in the Midwest discussed previously (see SIDEBAR - Biological Control), often reaches 3 m in height and individual plants can produce thousands of seeds. Blossey and Nötzold (70) planted seeds from its native range and seeds from North America in a common garden experiment and the North American plants were taller, produced greater biomass, and had lower concentrations of phenolic compounds (considered defensive against insect herbivores). In addition, larvae of European root-feeding weevils grew larger on North American plants. Purple Loosestrife has undergone significant genetic modifications over the 200 years it has been in North America.

Introduced plants may have the opportunity to hybridize with closely related species in their new environment. Johnson Grass (*Sorghum halapense*), a perennial invasive weed from the Mediterranean region, reproduces both vegetatively and by seed and can hybridize with cultivated sorghums with which its distribution is almost sympatric (identical) in North America (71). So far this has not been a significant problem; however, the hybridization of Johnson Grass with cultivated sorghums genetically engineered for herbicide resistance has the potential to produce a herbicide resistant weed (72).

Non-native insect herbivores in their new environments are exposed to a new set of potential host plants. The Soybean Aphid, first discovered in the U.S. in 2000, survives the winter as eggs on shrubs in the genera *Rhamnus* and *Frangula* (buckthorns). The species of *Rhamnus* found in China and Japan where the Soybean Aphid is native are present but rare in the U. S.; however, in the heart of the soybean growing region the Soybean Aphid found an alternative European species that is both abundant and widespread (*R. cathartica*) and also two natives (*R. alnifolia* and *R. lanceolata*) on which it can survive (73, 74). It is also exposed to other native and non-native *Rhamnus* spp. and fall migrants have been observed feeding and reproducing on both the European Glossy Buckthorn (*Frangula alnus*) and the native Carolina Buckthorn (*R. caroliniana*); however, successful overwintering has not been observed on these hosts (unpublished observations R. O'Neil and D. Voegtlin). It may be only a matter of time before aphids capable of overwintering on these hosts become a part of the North American population.

PROGRAMMATIC SOLUTIONS—WHAT IS BEING DONE?

Illinois is addressing the issue of invasive species through research, outreach, management, and policy. Research provides the basis on which management and policy decisions are based (e.g., see SIDEBARS on Biological Control and Building Barriers) and provides material for outreach and education. Much of that research is described in other chapters of this book. Outreach specialists such as those with INHS and Illinois-Indiana Sea Grant use these research findings to educate Illinois citizens on the biology and impacts of invasive species, and ways that individuals can reduce the introduction and slow the spread of these organisms. They do this through several venues including staffing booths at environmental events, visiting classrooms, giving presentations to hobbyist groups, and through publications including fact sheets, fliers, and Web sites (e.g., www.iisgcp.org/il-ans).

Illinois has several regulations regarding invasive species, and state officials examine the laws and regulations periodically to determine if they need to be strengthened. For example, it is illegal to release any aquatic life into Illinois waters without permission of the Illinois Department of Natural Resources (IDNR). It is also illegal to raise or sell aquatic species that are not on the Aquatic Life Approved Species List without review and permission by IDNR. Both of these laws are geared toward ensuring that invasive species are kept out of Illinois waters. Illinois also has regulations to protect terrestrial habitats and organisms including the Exotic Weed Act. This law makes it unlawful for any person, corporation, political subdivision, agency, or department of the state to buy, sell, offer for sale, distribute, or plant seeds, plants, or plant parts of non-native weeds without a permit issued by the IDNR. Similar laws exist for other terrestrial organisms. For the most up-to-date and comprehensive information on Illinois' regulations, visit the Web pages of the Illinois General Assembly (http://www.ilga.gov/). Likewise, the Illinois Noxious Weed Act, a state law designed to control highly invasive plants in agricultural landscapes, lists 10 species that are considered problematic by the Illinois Department of Agriculture, including mostly non-native species. This list also includes two native ragweed species (*Ambrosia artemisiifolia* and *A. trifida*) that are common in all 102 Illinois counties. The Noxious Weed Act indicates that it is the duty of landowners to control the spread of and to eradicate all noxious weeds; however, given the ubiquity of many of these species, particularly the ragweeds, it is impractical to fully enforce.

Management of invasive species is a major undertaking in Illinois with several state and local agencies actively involved. For example, IDNR biologists work in the field to eradicate and control invasive plants in natural areas.

Likewise, IDNR foresters work with private landowners to control invasive species on private lands to enhance these forests and ensure that the invasive species do not spread to other areas. In addition, a Vegetation Management Manual (Vol. 1, numbers 1–40), prepared as Management Guidelines by the Illinois Nature Preserves Commission, lists plant species that are invasive in Illinois natural communities together with recommended control methods (http://dnr.state.il.us/INPC/Management_guidelines.htm). On the aquatic front, the IDNR Division of Fisheries controls aquatic weeds in many places such as Mermet Lake in southern Illinois to ensure that they do not become a problem in other natural areas. IDNR also administers the Comprehensive Aquatic Nuisance Species Management Plan, which guides the state in addressing the aquatic invasives issue.

In addition to this active management, state and local agencies have formed several groups, which work together to address the issue of invasive species. For example, IDNR created the Aquatic and Terrestrial Nuisance Species Task Force, to address all invasive species comprehensively within IDNR. One committee of this is the Illinois Invasive Plant Species Council, which consists of biologists, nurserymen, landscapers, restoration biologists, field biologists, and agriculturalists, working together to prevent harmful intentional and unintentional introductions of invasive species, detect and respond rapidly to new invasives, and manage and restore areas in Illinois affected by invasive plants. Other partnerships formed to address invasive plants are Cooperative Weed Management Areas (CMAs). Currently there are four CMAs, which work across jurisdictional boundaries to control invasive plants. The New Invaders Watch List (75) is another example of a cross-jurisdictional partnership of government, non-profit, and volunteer organizations dedicated to the early detection and control of new exotic invasive plant and insect species in the Chicago Wilderness region.

While the state has played the largest role in the invasive species issue, the federal government has played a direct role in Illinois, too, specifically in the Army Corps of Engineers' construction of the electric dispersal barrier in the Chicago Sanitary and Ship Canal. This barrier is designed to restrict the flow of aquatic species between the Great Lakes and Mississippi River basins (see SIDEBAR—Building Barriers). In addition, the Midwest Invasive Plant Network (MIPN; http://mipn.org/) is a consortium of industry, state and federal government, research, and non-profit agencies that formed in 2002 from meetings and conferences highlighting problems with invasive species. The mission of the MIPN is to reduce the impact of invasive plant species in the Midwest with a focus on education and outreach. An important MIPN initiative involves early detection and control of potentially invasive species before they can become widespread (http://mipn.org/detectionresponse.html).

Things are happening on a local basis, too. The City of Chicago's Department of the Environment does public outreach and education events and in 2007 has passed an ordinance banning possession of certain aquatic invasive organisms (76). Chapters of the Illinois Native Plant Society try to control invasive plants in small areas and promote the use of native species in landscaping to minimize invasion problems. Finally, the Chicago Botanic Garden has a policy of no invasive species in its permanent outdoor collection (77).

THE OUTLOOK FOR ILLINOIS AND THE MIDWEST

Similar to other midwestern States, the changes to the flora and fauna of Illinois from non-native and invasive species has been staggering. Non-native plants now comprise about 31% of the total flora (17) and approximately 540 animals (Table 12.2) are now established in the state. Given the increase in global trade, limitations on the inspection of international shipments, and even indifference in some cases to the problem, there may not soon be a significant decrease in the number of non-native invasive species that arrive in the Midwest. For example, there has been a steady increase in the proportion of non-native organisms since European-American settlement times among all species groups. Nevertheless, it remains imperative that Illinois and other midwestern states do all they can to prevent the introduction of additional invasive species, and when new non-native species are found, to do all that can be done to eradicate them. This approach can be much more cost effective than waiting until an invasive species becomes widely established. This preventative approach will demand the anticipation of potential pests, policy development and enforcement, research, and a major education/public outreach effort. An educated citizenry can assist in monitoring and is much less likely to participate in practices that may introduce exotics.

Illinois must also deal with the ever-increasing impacts of the non-natives presently established, expanding their range, and degrading local environments. Long-term reduction in these problems will take major commitment and financial support for management, education, and research. Biological control, and other actions such as physical barrier construction or pesticide/herbicide applications, may be feasible for some of these invasive species and should receive scrutiny as control plans are developed and implemented.

Table 12.2. Numbers of established non-native animal species in Illinois.

Molluscs	6
Crustaceans	2
Insects	~500
Fishes	22
Mammals	1
Birds	10

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CHAPTER 13

History and Progress of Ecological Restoration in Tallgrass Prairie

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OBJECTIVES

What were the beginnings of ecological restoration, how has the field of restoration ecology developed, and what role does science have in its application? This chapter explores the development of restoration ecology, centering on early efforts to establish tallgrass prairies and the contrasting approaches taken in the past by practitioners and researchers. How the scientific process can provide guidance to practioners of ecological restoration is addressed. Insights from evolutionary history, plant and animal interactions, and future trends also are discussed.

ECOLOGICAL RESTORATION AND RESTORATION ECOLOGY

During the past century there has been a growing recognition that functioning natural ecosystems, and the important "ecosystem free services" they provide to living organisms, are constantly being diminished (1, 2, 3). This awareness has resulted in increased interest in ecological restoration. Ecological restoration has been defined as "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed" (4). The broad goal of ecological restoration is a stable ecosystem that is maintained by sustained ecosystem functions, including interactions among living organisms, such as mutualism and predation, hydrological cycles, soil building and maintenance, energy flow, and chemical cycling (5). Motivations for restoration of ecosystems vary. They include compliance to satisfy mitigation required by governmental agencies for environmental damage resulting from public works projects and development on private lands or restoring ecosystem-free service benefits on degraded lands. For volunteers involved in restoration projects, the stimulus can be "spiritual renewal" experienced by persons involved in restoration activities (6). The Society for Ecological Restoration International (SER) was founded in 1988, and now has 2,300 members distributed among the 50 states in the U.S. and in 37 countries. Ecological restoration is carried out by non-profit organizations, such as The Nature Conservancy and the Audubon Society, federal, state, and municipal governments, and commercial organizations (4).

The beginning of ecological restoration may have been initiated without substantial input from science or methods that have a strong science base. Although research through the application of the scientific method has made important contributions to the understanding of ecosystem restoration, the specific role that research plays in restoration of ecosystems has been the focus of considerable discussion. *Restoration Ecology*, the scientific and technical journal published by SER, was initiated in 1993. Of the first 13 issues of the journal, 5 issues contained editorials or comments focusing on the role of science in restoration ecology (7, 8, 9, 10, 11, 12). In most years of publication, there was at least one issue with a comment or editorial considering the role of science in restoration ecology. In an insightful article Hobbs and Norton (13) wrote, "What is clear is that restoration ecology has largely progressed on an ad hoc, site- and situation-specific basis, with little development of general theory or principles that would allow the transfer of methodologies from one situation to another."

Four ingredients necessary for ecological restoration to be successful include: 1) a vision of what the ecosystem being restored should be like when the restoration is finished, 2) an understanding of the ecological processes needed to restore and maintain the ecosystem, 3) knowledge of the specific restoration skills and management practices that are needed, and 4) public support for goals of ecological restoration and confidence in the principles that form the scientific basis for restoration. Research can contribute to all of these components.

THE ROLE OF SCIENCE

The need to define a role for science in restoration ecology apparently is related to the historic development of restoration ecology. Defining a specific time when restoration ecology began would be like looking at the diffuse root system of a perennial grass and declaring a single root apex to be the originating branch of the root. In grasses, the primary root disappears in a relatively short period of time following germination. The root system that develops is composed of numerous adventitious roots, none of which can be declared to be the primary root. The beginning of restoration ecology is no less diffuse.

The restoration of the Curtis Prairie, at the University of Wisconsin-Madison Arboretum, beginning in 1934, is often cited as the first effort to restore a native community (14, 15). While this statement is probably correct, to deem this effort the beginning of restoration ecology would require a narrow view of ecological restoration. This conclusion would ignore practical efforts at rehabilitation of degraded lands such as reforestation or planting of vegetative cover to stabilize eroded lands ravaged during the "dust bowl" of the 1930s. These rehabilitation

efforts predated or occurred concomitantly with the beginning of the Curtis Prairie and often involved the use of workers from the Civilian Conservation Corp as did the early years of the restoration of the Curtis Prairie.

Restoration of the Curtis Prairie, an example of a reconstruction (see Chapter 14 of this volume), began without much assistance from science. However, it was Aldo Leopold, a scientist, who proposed that the arboretum be a microcosm of the presettlement landscape of Wisconsin. This proposal served as an impetus for the development of the prairie that historically was a component of the southern Wisconsin landscape. As described later, information derived from scientific methods was not an important factor in the restoration of Curtis Prairie until more than a decade after the project began. The initial efforts at restoration were accomplished by persons who proceeded much as the practitioners of restoration ecology do today. Consequently, the restoration was not a scientific experiment to test a specific hypothesis with treatments and a control. Even though some records were maintained as the planting occurred (16, 17), the information derived was not the sort that would allow conclusions to be made about which planting methods were most successful.

Similarly, the prairie at the Fermi Accelerator Laboratory at Batavia, Illinois, which is arguably among the largest prairie restorations, mostly proceeded as an effort to make a prairie, not as a scientific study (18, 19). The goal was not to test methods of establishing prairies or to necessarily provide good documentation about the restoration process. This is not to say that efforts of this kind have not provided useful information about how restorations should proceed—they have. For example, "The "do's" and don'ts" of prairie restoration" by Schramm (20) is largely information derived from practical experience doing restoration. Schramm tells us what has worked in his experience. What we do not know is the precise conditions under which his prescription worked or what other methods were tested under similar conditions and found to be lacking.

In the first volume of *Restoration Ecology*, the president of the Society for Ecological Restoration made a distinction between restoration ecology and ecological restoration (9). Restoration ecology is a "broad subset of the entire field of ecology, including its theories, tenets, and body of knowledge." Ecological restoration "is the practice of restoring and managing ecosystems." Higgs (21) added specificity to the definition of ecological restoration and described it as "the entire field of restoration, including restoration ecology, politics, economics and cultural dimensions." While there is considerable overlap between restoration ecologists and restoration practitioners, restoration ecology provides the theoretical basis and the principles governing the applied processes of restoration. While restoration can proceed without theory, its progress tends to be limited to specific applications without development of principles.

The features (six cardinal points) that delineate a scientific approach to restoration were outlined by Bradshaw (7). Each point with his explanation is summarized below.

1) **Awareness of other work**. Being aware of published literature that describes similar work and/or establishes general principles, regardless of where in the world the work was conducted. 2) **Preparedness to carry out proper experiments to test ideas**. Experiments should test what happens when a treatment is applied, but also the result when there is no treatment (i.e., there should be controls).

3) **Preparedness to monitor fundamental parameters in a restoration scheme**. It is necessary to monitor the change in the structure and function of ecosystems being created. This can be accomplished by identifying and monitoring critical components of the system during restoration.

4) **Further tests and experiments suggested by these monitoring observations**. Follow-up experiments are often a necessary part of a restoration program to correct deficiencies identified during restoration.

5) **The restoration of functioning ecosystems in which a variety of species is involved.** The behavior of species is important to understanding the function of ecosystems. Experiments should be conducted that provide information about the behavior of species during restoration.

6) **Publish results**. Restoration ecologists need to state what was done and describe how the results obtained relate to other sites. Without a body of literature that documents restoration studies, each restoration study must begin anew.

To the scientific community the approach that was being used by some restorationists to establish new paradigms for restoration ecology did not measure up to these standards and was neither basic nor applied research (8, 22, 23). Some work appeared to be a return to subjective appraisal of ecological systems that had characterized the early history of vegetation ecology. This dichotomy to the approach of restoration has been recognized by the Society for Ecological Restoration that now publishes two journals. One journal is mostly focused on publishing ideas and practical applications (*Restoration and Management Notes*—currently titled *Ecological Restoration*) and the other journal (*Restoration Ecology*) publishes scientific studies.

The driving forces for the nonscientific approach taken by some restorationists are probably a mix of unfamiliarity with scientific methodology and a sense of urgency that we do not have the time to wait for results of rigorous scientific studies to provide information about how restoration should be carried out. This also has a practical dimension because there are limited resources for research and restoration on far more lands than can be scientifically investigated. This approach to restoration was supported by Cabin (24) who wrote, "Thus, if one's goal is to accomplish ecological restoration as quickly and efficiently as possible, a trial-and-error/intelligent tinkering-type approach might often be better than using more rigorous, data-intensive scientific methodology." The urgency stems from concern for the rapid degradation of natural landscapes, which we all share.

Scientists interested in restoration ecology must define what kind of research needs to be conducted (25). They must also ensure that their ideas and approaches to delineating concepts and principles are embraced by the practitioners and the public. In some cases, it appeared as if the results of scientific studies were rejected because

restorationists were able to generate greater support in the popular press for their ideas than scientists. This point is illustrated by Stevens (26) in his treatments of the differing views held by scientists and some restorationists regarding the origin and nature of savannas. Stevens (26) documents the superb accomplishments of advocates of the non-scientific method of inquiry in engaging the public in the concepts of restoration and motivating them to become involved in restoration activities. The perspective of scientists received fair treatment in Stevens' book. However, science appeared to be overshadowed by the valuable accomplishments of restorationists in areas other than science (e.g., developing volunteer networks, stimulating public interest and support, and generating creative ideas about restoration). These accomplishments appeared to increase the credibility of restorationists in the savanna debate. At that time, the non-scientific approach to restoration seemed to be gaining some support even from within the scientific community (27).

INTEGRATING SCIENCE WITH PRACTICE

Practitioners and restoration ecologists have made, and will continue to make, valuable contributions to ecological restoration. Nevertheless, it is important to understand how the approaches to solving problems taken by the two groups differ to make the most effective use of the information they generate. Greater effort should be made to foster dialogues between research scientists and restorationists (28). Criticism that Risser (29) made of ecologists and their interactions with resource managers might in some instances also apply to restoration ecologists and their relationship to restorationists: "It is patently unfair to publish papers in conventional scientific format and then criticize the less sophisticated consumer for not finding and/or not using the information correctly. As ecologists, we must change our approach from that of criticism to one of assistance." Risser further proposed that research scientists include a summary of their work that clarifies how it has practical applications for resource managers. The journal of *Restoration Ecology* currently requires that authors summarize the practical relevance of their studies at the end of each article under the heading, "Implications for Practice." On the other hand, restorationists should increase their familiarity with the growing body of literature which has direct application to ecological restoration, but is published in sources they may not usually search. While ecological restoration can be done as an "ecological garden" (24, 30), it benefits from information and ideas generated from research carried out by restoration ecologists.

The development of adaptive management potentially provides a bridge between the approach used by restoration ecologists and restoration practitioners. In adaptive management, restorations are deliberately designed as experiments. It begins with an assessment of the objectives of the restoration, the resources needed and methods available to achieve these objectives, and performance measures that could be used to monitor progress in achieving the objectives. From the assessment, a restoration plan, an experimental design with testable hypotheses and predictions, and a monitoring plan are developed. The restoration plan is implemented and progress towards achieving the restoration goals is monitored. Evaluations are made of progress by analyzing monitoring data to determine if the restoration goals are achieved, if hypotheses are supported or rejected, and whether predictions based on hypotheses were accurate. If goals are not met, then restoration practices, policies, and plans are adjusted based on the information obtained. Thus, adaptive management allows restorations to proceed and be adjusted as needed, based on the results of experimental data (31).

RESTORATION ECOLOGY AND RESTORATION OF PRAIRIES

In this section, the development of restoration methodology for the tallgrass prairie ecosystem is examined. This examination illustrates some of the ways that research has contributed to understanding this restoration process and provides model endpoints that serve as the basis for determining the success of restoration efforts.

THE FIRST PRAIRIE RESTORATION

The first major effort at prairie restoration began at the University of Wisconsin-Madison Arboretum in 1934 with the restoration of the 25-ha Curtis Prairie (14, 16). Prior to European settlement, most of the area occupied by the arboretum was oak savanna. The area now occupied by the Curtis Prairie was settled by Europeans in 1837. It was regularly plowed and planted to field crops until the early 1920s (32). The abandoned field was then used as a horse pasture from 1927 to 1932, during which time the site became dominated by Kentucky and Canadian bluegrasses and was devoid of prairie plants.

Under the supervision of Theodore Sperry, Civilian Conservation Corp workers collected sods from local prairie remnants. The sods supposedly contained a single species and were planted in monospecific blocks (17). The sods, however, contained a mixture of prairie species in addition to the target species, so the monotypic nature of the plots was never perfect (14). The sods were planted among the bluegrass, generally with little or no pretreatment of the site. The initial planting program ended in 1940 and no additional plantings were made until 1950 (14 ,16, 17, 32, 33).

In the 1940s and 1950s, several studies were conducted that generated information needed for the restoration of native prairies. Intensive examination of the composition of native remnant Wisconsin prairies (34, 35, 36) provided data about what the restored community should resemble. Additional research included studies of seed germination of prairie plants, pretreatment of the planting sites, and the use of cover crops for prairie restoration (37, 38, 39, 40, 41).

One of the most important discoveries of the early studies of prairie restoration at Wisconsin Arboretum was the successful use of fire as a management tool (42). Fire, appropriately used, was found to be effective in retarding the growth of cool season (C3 photosynthetic pathway) exotic weeds, such as Kentucky Bluegrass, while enhancing

the growth of the warm season (C4 photosynthetic pathway) prairie plants and their flowering and seed set (32, 39, 40, 43, 44, 45). Since 1950, the arboretum prairies generally have been burned biennially (Figs. 13.1 and 13.2).

Monitoring the progress of the prairie restoration at five-year intervals began in 1951 using meter-square quadrats to obtain presence-absence plant data. The quadrats are located on a 50-ft x 50-ft grid system that is distributed over the prairie. By 1961, portions of the Curtis Prairie were similar to native prairie stands (Fig. 13.3) in terms of the number of indicator species and summed frequencies of the prairie species (14, 46).

Figure 13.1. An early precribed burn conducted on the Curtis Prairie on the University of Wisconsin campus near Madison in 1950. Photo from University of Wisconsin.

Figure 13.2. A prescribed fire in the Curtis Prairie in 1970. Photo by R. Anderson.

The 20-ha Greene Prairie, another reconstructed prairie at the Madison Arboretum, is considered to be one of the best examples of restored prairie anywhere. It is comparable in diversity to good quality native remnant prairies of equivalent size and occurring on similar soils (14, 45, 47). Plans for the establishment of the prairie were formulated in 1942 by Henry Greene, for whom the prairie is named. Planting of the site was carried out almost entirely by him. Greene considered the original vegetation of the site to be of the sand prairie-oak opening type (48). However, the area supports prairie vegetation ranging from dry to wet prairie (49). Before the site was acquired by the arboretum in 1941, sporadic attempts were made to farm the entire area now occupied by the prairie. Nevertheless, farming did not completely eliminate prairie species and one corner of the site was relatively unaltered (49). Intensive efforts at prairie restoration began in 1945 and continued through 1952 (48, 50). Prairie species were introduced on the site by planting seed or seedlings grown in the greenhouse, transplantation of small blocks of prairie sod, or by the introduction of mature prairie plants (37).

Henry Greene was an excellent field botanist, although his training was in plant pathology. He apparently became extremely proficient at identifying vascular plants, which served as hosts for the fungi he studied (personal communications, Grant Cottam). His knowledge of the habitat requirements of prairie species was exceptional and he collaborated with the well-known plant ecologist John Curtis on several studies (34, 37, 51). When Greene planted species on the site, they were planted in habitats that he thought were best suited to their ecological requirements. It is of interest that Henry Greene recommended that forbs be planted and established before grasses were planted (49), a recommendation that has been followed for more recent restorations. Like the Curtis Prairie, the Greene Prairie has been systematically sampled at five-year intervals using quadrats positioned at standard locations (14, 49).

Within the Greene Prairie changes in quadrat frequency for prairie indicator species, between 1952 and 1966, revealed that species' abundances and distributions

Figure 13.3. Curtis Prairie during July of 1971. Photo by R. Anderson.

shifted within sectors of the prairie based upon the availability of soil moisture. Drier sites occurred on upper slope areas and had sandy soils and lower topographic areas had soils with a finer silty texture and were wetter. Species changes were toward the soil and drainage patterns most similar to the native prairies in which they naturally occurred (49). These results indicated that, over time, species occurring on a restoration site may segregate so they occupy sites most suitable for their optimum growth. During the same period of time, weedy exotics decreased in abundance, while the abundance of prairie species increased. Over the decades, the Curtis and Greene restored prairies increased their similarity to native prairies, yet remained somewhat imperfect replacements as they contain few of the grassland animals and non-native plant species (e.g. Kentucky Bluegrass, sweet clovers, Poison Parsnip, and others) are abundant in portions of the prairie.

As a footnote to the efforts and success of restoring the Greene Prairie, the *Friends of the Arboretum Newsletter* (January 1996) carried an article describing urban development adjacent to the prairie that produced excessive storm water runoff and seriously damaged portions of the prairie. Efforts are being made to mitigate these effects, as well as those anticipated to occur, as a result of future urban development projected to occur immediately south of the prairie (52). These problems point to the need for constant vigilance to insure the integrity of natural or restored ecosystems.

INTEREST IN PRAIRIE RESTORATION GROWS

From the late 1960s and into the 1970s, there was an expansion of a movement to restore native prairies and plant native grasses and legumes for roadside cover, forage for domestic livestock, and as a landscape planting (53, 54, 55, 56, 57). The methods used by these restorationists varied from transplanting prairie seedlings grown in greenhouses to drilling seeds of prairie species into sites prepared by tilling and disking to control competing weeds. The methodology outlined by Schramm (56) became the standard guide for many restoration efforts and was essentially the procedure recommended for the next two decades by other references that were often used by groups and individuals interested in restoring prairie (e.g., 58, 59).

The recommended restoration procedure involved intensive site preparation to remove any existing vegetation. For example, on sites with well-developed sod, fall plowing, followed by additional cultivation in the spring, was recommended to control weedy exotics before plantings were made. Locally collected or commercially purchased seeds were provided with cold-moist stratification and hand broadcast or drilled on the site. Specially designed drills were developed to handle the native prairie seeds with their numerous bristly structures (eg., trichomes and awns). Planting usually occurred in middle to late-spring and occasionally in the early part of the summer, after the extensive cultivation to control weedy plants. Late planting risked exposing seeds to insufficient moisture to allow seeds to germinate and successfully establish seedlings. Prescribed burning in the spring was recommended when the site had sufficient fuel to carry a fire, usually in the second spring following planting. Relatively high density plantings of grass seeds were initially recommended (one to three dozen grass seeds per square foot) to ensure rapid development of a restored prairie on the site (56). However, many of these techniques have been modified or are no longer used by restorationists (60).

CHANGING VIEWS ON PRAIRIE RESTORATION

From the beginning of prairie restoration in the 1930s and continuing through the 1970s, with some exceptions, the focus had been on establishing a plant community with relatively little thought given to other groups of organisms. The net result was that restored prairies were more like prairie gardens than functioning ecosystems. The high seeding rates for grasses that were used, the difficulties associated with obtaining sufficient quantities of forb seed, and the planting of forb seeds at inappropriate depth by seed drills set for planting grasses, resulted in nearly monotypic stands of prairie grasses with low abundances of forbs (61, 62). Nevertheless, some very high-quality restored prairies were established during this era such as the partially hand planted Schulenburg Prairie at the Morton Arboretum in northeastern Illinois (55).

By the 1980s, the focus of research and restoration efforts were broadening to include

considerations of other groups of organisms, such as invertebrates (64, 65, 66), birds (67, 68), small mammals (69, 70, 71), large mammal herbivores (72, 73), burrowing mammals (74, 75), fungi (76), and mycorrhizal fungi (77, 78, 79). Initially, many of these groups of organisms were studied independently without considering how they interacted to affect functional aspects of ecosystems or the evolutionary processes that resulted in these interactions. It has been only in the past two decades that a more comprehensive view of prairie restoration began to emerge. While the interaction between science and ecological restoration has been weak in some areas (24), the melding of research and restoration of prairies has been strong and the potential for science to contribute information useful to prairie restoration is high.

MODIFYING OUR VIEWS OF PRAIRIE RESTORATION

USE OF FIRE

The increased amount of information about prairies (80) resulted in modification of some standard management practices. For example, even though fire is the most widely used tool in prairie restoration and management, deciding on an appropriate grassland management fire regime to accommodate the wide array of responses prairie species have to fire is complicated as illustrated by the response of invertebrate species. Invertebrate response to burning is dependent upon a number of factors, such as how the microclimate and structure of the vegetation is changed after fire, the location of invertebrates when the fire occurs, and how well the invertebrates adapt to the changed environment post fire (63, 64, 81, 82, 83). For example, during a fire that had surface temperatures of 200° C, species of spiders that were active on the soil surface were eliminated, whereas species in subsurface burrows, under rocks, or in the bases of caespitose (clumped) grasses survived the burn (63). Butterflies (84, 85), and leafhoppers decrease in abundance after fire (64), but mixed responses of species to fire were reported for mites (81), collembolans (64), and grasshoppers (86). As the frequency of fire decreased, some grasshoppers feeding on forbs increased in frequency; however, other species of grasshoppers increased after fire and/or showed rapid recovery post burning (83, 86).

Thus, a single management prescription that will be acceptable for all invertebrates is not likely to be feasible. Some entomologists think that current burning practices harm prairie insects, and if continued, might result in a substantial number of species becoming extirpated (87, 88). To conserve butterflies, Swengel and Swengel (85) recommended that permanent non-fire refugia be established and managed with other methods, such as brush cutting and mowing, if necessary. In contrast, Panzer and Schwartz (89) concluded that conserving insect biodiversity is compatible with the current fire rotational plan used in Illinois (burn about every two to three years). In the extensive historic grasslands, fires left some areas unburned each year and these areas would have provided refugia for fire sensitive insects. Burning fragmented remnant prairies or restorations under current conditions often results in all or nearly all of the intended burn unit being treated with fire. To provide unburned refugia for insects sensitive to fire, it is recommended that only 30% to 50% of a site be burned, with the assumption that fire sensitive species can reinvade the burned area during the growing season following the burn (65, 89, 90, 91). Leaving areas missed by the fire unburned, burning in the early morning to reduce intensely hot fires, and conducting spring burns to retain grass clumps for insects to use as wintering sites are additional recommendations to favor sensitive insects (65).

INCOPORATING EVOLUTIONARY HISTORY

New approaches to restoration should consider the evolutionary relationships among organisms that resulted in interactions that are essential to a functionally stable ecosystem. The coevolution of large herbivores and grassland species may provide the best example of how an evolutionary view of organism interactions can be applied to restoration. Grasses are among the dominant species in prairies and are adapted to drought, fire, and grazing. Having below-ground perennating organs may be a pre-adaptation to all three of these factors. However, there are other features that indicate a co-evolutionary relationship between grasses and grazers. These features include presence of silica in epidermal cells in grasses and hypsodonty (high-crowned cheek teeth) in grazers, both of which appeared in the Eocene, and compensatory aboveground growth following grazing (72, 73, 92). The expansion of grasslands and savannas worldwide post-Miocene was associated with the radiation of large mammals adapted to grazing and grasslands and savanna habitats (72, 73, 92).

In North America, the primary large mammal grazer since the end of the Pleistocene has been the bison. The bison is considered by some to be a keystone species (93). However, it has been only in the last two decades that grasslands large enough to permit bison to function as they did historically became available to study (73). Burning and grazing accelerates the rate of mineralization of inorganic nutrients, such as nitrogen, but without volatilization, which contributes to nitrogen loss from prairies (94). For example, grazers like bison are effective in changing some recalcitrant forms of organic nitrogen to urea that is easily converted to ammonia, which plants can readily use. The increased availability of inorganic nutrients can enhance grassland productivity (93).

Bison grazing can increase plant diversity and spatial heterogeneity of grasslands (93, 95), which has been shown to increase the diversity of grassland birds (67, 68, 96). While grasses are the dominant plant species of prairies, it is the forbs that contribute most of the species richness (97). About 90%–95% of the diet of bison is grass and they consume few forbs. Bison graze in patches, which they repeatedly graze and abandon when grass forage is reduced. Grazed patches that regrow during the growing season are preferred by bison over ungrazed areas, because grazed patches contain higher-quality forage. Repeat grazing of patches reduces the competitiveness and dominance of grasses, thereby encouraging forbs and increasing diversity

(73, 93). Grazing affects fire patterns by producing a patchwork of vegetation varying from heavily grazed areas with low fuel loading to sparsely grazed areas with heavy fuel loading. The varied fuel pattern results in a mosaic of intensely and lightly burned areas that favors high diversity of small mammals (71) and insects (89, 98).

Grazing as a grassland restoration tool has not been extensively applied, especially in the eastern portions of the tallgrass prairie. However, grazing returns a historical function to grasslands that has the potential to increase grassland diversity. Burning and grazing are combined in a management practice termed "patch-burn grazing," which may enhance grassland diversity (99). In this management practice, grazing animals (cattle or bison) graze freely across the prescription area that has recently burned and unburned patches. Cattle, as well as bison, prefer to graze on burned areas more than in unburned areas in the first year after the fire. The intense grazing in the burned area creates openings and reduces the competitiveness of dominant C4 grasses (e.g. Big Bluestem and Indian Grass) that are preferred forage over forbs for both bison and cattle and encourages the growth of the unpalatable forbs (100). On restored prairies with high dominance of C4 grasses and low forb diversity, the heavily grazed and burned areas could be sown with forb seeds to enhance species richness (99, 100). In the following year, the pattern of burned and unburned patches is reversed allowing the seeded forbs to become established. However, grazing is not an option on all prairies because of size limitations and other factors.

Leach et al. (101) suggested that historically in the eastern portion of the tallgrass prairie bison were not as abundant as they were on the mid- and shortgrass prairies. As a consequence they suggest a strong interaction between grazers and eastern tallgrass prairies did not evolve and there are plant species sensitive to grazing, although this issue remains unresolved (102, 103). Nevertheless, depending upon restoration goals, grazing may be a useful restoration tool even if there is uncertainty about whether it was historically important in a region. For example, the Midewin National Tallgrass Prairie in northeastern Illinois has the largest nesting population of Upland Sand Pipers in Illinois. During the time of nesting the bird requires short grass and a relatively unobstructed horizon (67). The nesting habitat for the grassland bird is maintained by cattle grazing on cool season domestic grasses. An important restoration question that needs to be determined is whether native grazers or their surrogates can produce similar habitat structure utilizing native prairie.

Elk and White-tailed Deer historically may have been important in retarding woody plant invasion into grasslands and these species or their surrogates (goats and cattle) may be useful to control woody vegetation invasion into prairies. In central Illinois, the ParkLands Foundation uses cattle grazing to control invasion of woody exotic shrubs [e.g. Autumn Olive (*Elaeagnus umbellata*), Amur Honeysuckle (*Lonicera mackii*), and Multiflora Rose (*Rosa multiflora*)] into cool season domestic grass and native prairie grass plantings that are maintained for grasslands birds. Similarly, cattle grazing may be useful to retard invasion of woody plants into loess hill prairies in Illinois. Between 1940 and the present, more than 50% of the area of hill prairies was lost, largely due to the invasion of woody species, which can reduce flammable fuels and suppress prairie plants by shading (see Chapter 4). Even hill prairies that received periodic burning experienced a decline in area due to woody invaders. In the past century, most hill prairies were subjected to grazing, and heavy grazing by cattle can degrade them. However, control of woody invaders may be achieved by moderate to light grazing (104). On similar vegetation in Wisconsin, Curtis (36) stated that "... some dry prairies on thin soil hillsides are known which have been grazed continuously for over a century but they are still dominated by the two grasses mentioned above (Side-oats Grama Grass and Little Bluestem) and still contain a number of their typical forbs…" Thus, grazing may have a role to play in restoration and management of prairies in areas where our limited evidence of historic patterns suggests grazing may not have been an essential part of the prairie ecosystem.

THE FUTURE OF PRAIRIE RESTORATION

Public interest in prairie restoration has grown during the past three decades, and there has been a union of interest in prairie restoration among scientists, federal and state personnel involved in management and restoration of prairies, private organizations and foundations, and the general public. This is illustrated by the expanded attendance and diversity of expertise represented at the North American Prairie Conferences, which have been held at two-year intervals since 1968. The first conference was held at Knox College (Galesburg, Illinois). The conference was attended by 120 people, including scientists, government personnel, naturalists, and lay people. Subsequent conferences have attracted a large portion of the attendees from the general public, many of whom often have gained experience in prairie restoration through volunteer programs. The size of the conferences has grown to as many as 500–600 attendees. There has also been the development of commercial nurseries and landscaping companies that specialize in the planting of prairies and/or selling of prairie plants or seeds. In Illinois, private grass roots organizations, such as the Grand Prairie Friends, Save the Prairie Society, and the ParkLands Foundation, work to save remnant prairies and are involved in prairie restoration. Nationally, private organizations including The Nature Conservancy, the Audubon Society, and federal agencies such as the Natural Resource Conservation Service promote prairie restoration and protection of remnant prairies. Home owners and private corporations are using native prairie plants for landscaping and in several states prairie grasses and forbs are planted along roadways. Prairie plants, especially grasses, are extensively planted in the Conservation Reserve Program to protect and rebuild erodable soils. This broad base of support for saving remnant prairies and prairie restoration has laid the ground work for continued interest in understanding the ecology of prairies and prairie restoration.

SUMMARY

As a formalized body of knowledge, ecological restoration is a recent phenomenon, with scientific journals first addressing the topic in 1981. Ecological restoration has borrowed from the principles of ecology, used practical information generated by practitioners and depends upon them for meaningful application of principles developed by restoration ecologists. Several authors (105, 106, 107, 108) proposed that restoration ecology can serve as a heuristic experience and a test of ecological theories, because it provides researchers with the opportunity to test their ideas on the nature and functioning of ecosystems. They further suggested that in the process of putting an ecosystem back together we learn about the structure and function of that system. Given the extensive alteration of ecosystems that is likely to occur worldwide in the next several decades, the importance of restoration ecology and ecological restoration should only increase because of the potential for restoration to generate stable self-sustaining ecosystems that will continue to provide ecosystem-free services. Cottam (14) stated, "In prairie restoration there is no substitute for knowledge..." and it is apparent that this statement applies to all restorations and should guide ecological restoration as we approach the challenges presented by alteration of the earth's environment on a global scale.

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CHAPTER 14

Restoration in Terrestrial Plant Communities—Examples From the Prairie-Forest Transition Zone

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OBJECTIVES

Considerations and results of ecological restoration conducted at the population, species, and community levels of organization are the foci of this chapter. Examples will come from prairie, savanna/open woodland, and forest communities.

INTRODUCTION

From forest to savanna, prairie and wetland, trends since settlement have included a dramatic reduction in habitat and habitat quality (e.g., Chapters 4 and 5). The landscape in heavily agricultural states such as Illinois has been so greatly reconfigured as to place severe limitations on the potential for natural processes of recolonization to compensate for patterns of habitat destruction. Forested lands in Illinois have recovered somewhat from a period in the late1800s and early 1900s of unsustainable harvests and now are about one-third of the original extent, but very little remains that has not been degraded by past logging, livestock grazing, altered natural disturbance processes, and infestations of exotic species. For the most part, habitat loss and degradation for all community classes has been unidirectional. Reversing these trends, particularly in a highly fragmented landscape, requires the application of ecological restoration. The topic of ecological restoration is vast in scope and scale; to address issues in a single chapter, selected examples of restoration at different ecological scales will be covered rather than a comprehensive account of restoration at each level of ecological organization for each major habitat type. Exotic species infestations pose some of the greatest threats to sustainable native biodiversity and are addressed in Chapter 12.

Disturbance is a natural component of all habitats and many habitats are dependent on certain disturbance types for maintenance of diversity and compositional characteristics (e.g., fire in grassland, savanna, and woodland; flooding in bottomland forests). However, when the magnitude of disturbances in a natural community exceeds levels of tolerance for members of the species pool, this can result in degradation of that natural community. Absence of specific disturbances to which some communities are adapted also can lead to degradation of the system.

Ecological restoration ideally is a science and management-directed process of habitat recovery (see Chapter 13) when perturbations lead to degradation of the original, baseline condition of a natural community. Because ecological restoration can occur at several different spatial scales, different levels of ecological organization (e.g., populations, species, communities, landscapes), and be directed towards varying degrees of habitat degradation, terminology varies accordingly. However, in this relatively young science there remains inconsistency in how the terms have been applied (e.g., 1, 2, 3). As adopted by practitioners and ecologists locally in Illinois, the terms Restoration, Rehabilitation, Reconstruction, and Reclamation have been applied to situations characterized by increasing levels of habitat degradation. Restoration, while often used as a general term (4), also can have a specific meaning. When perturbations in a natural community result in relatively minor habitat degradation, there remains the possibility to reverse the trends and the community can recover to something similar to the baseline (i.e., presumed presettlement) condition because the species pool has not been greatly altered. This is ***Restoration*** (Fig. 14.1) and the rationale for the presettlement time frame is made in the introduction to Chapter 4. An example is application of prescribed fire in tallgrass prairie where woody encroachment has occurred. Where the magnitude, intensity, or duration of perturbations have occurred to the extent that, for example, many taxa in the original species pool have been replaced by more ruderal taxa (i.e., weeds and non-native species), the opportunity for full restoration is restricted. This particularly is true in a highly fragmented landscape such as Illinois' (e.g., 5) where the opportunities are limited for species immigration to compensate for declining or absent taxa. Through intensive management, it is possible the community can regain many characteristics of the original system; however, differences may remain.

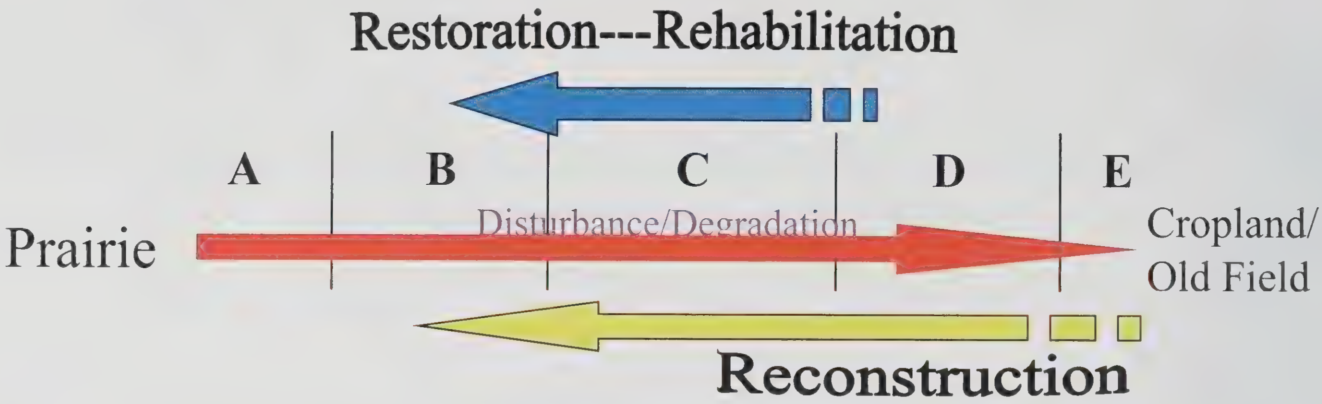

Figure 14.1. Diagramtic representation of the processes of degradation and opposing trends of restoration, rehabilitation, and reconstruction within the habitat-quality grades implemented for the Illinois Natural Areas Inventory (81).

Rehabilitation is a term applicable to this type of restoration. If the system has been degraded further to the point where little remains of the original natural community (e.g., cropland or other intensive land use), the only path of recovery to something resembling the original land cover is through the process of ***Reconstruction***, or Habitat Creation. An example would be a prairie planting on previously cultivated prairie soils. ***Reclamation*** is a term appropriate for partial recovery of highly degraded areas such as strip mined lands where vegetative cover is restored but without specific regard to the original community type. While wide agreement on these definitions remains unmet, as outlined here they encompass the full-range of activities that fall under the general topic of ecological restoration.

RESTORATION OF SPECIES AND POPULATIONS

CONSIDERATIONS OF PLANT BREEDING SYSTEMS IN PRAIRIE RECONSTRUCTIONS

Prairie in North America (Fig. 4.1) once covered about 137,000,000 ha (338,527,000 acres) including 68,371,000 ha (168,944,741 acres) classified as tallgrass prairie. Today fewer than 2,600,000 hectares of tallgrass prairie remain in North America (6). Most of this decline is the result of two activities, agriculture and urban development, which started during the mid-nineteenth century and continues to this day. About 99.99 percent of tallgrass prairie has been lost or degraded in Illinois, similar to other states in the eastern portion of the tallgrass prairie. Of the nearly 8 million ha (19,713,123 acres) of prairie historically in Illinois, only about 1,010 ha (2,496 acres [0.013%]) remain in a relatively undegraded condition (see Chapter 4). Most of this decline is the result of agriculture and, locally, urban development. Because so little prairie remains in Illinois, and persisting remnants primarily occur as small isolated fragments (see Fig. 4.4), prairie reconstruction can provide a way to increase this lost habitat.

Prairie reconstructions have increased throughout the Midwest. In Illinois, over 5,000 ha (12,355 acres) have been planted and more than 55,000 ha (135,905 acres) have been proposed for reconstruction by local, state, or federal agencies (7). Many of the reconstructions have been developed with an emphasis on plants, assuming other species will follow once the prairie is established. However, many sites still are struggling to meet goals of overall diversity (e.g., fungal and animal species). Although a significant number of prairie plant species have been successfully established in these reconstructions, little is known about their population dynamics and/or reproductive success and part of this is due to incomplete knowledge of plant-animal interactions, particularly pollinator species.

Plant populations are made up of individuals that belong to the same species and live in the same area. The establishment of reproductively viable populations in prairie reconstructions is essential for successful plantings. Typically, when the subject of population establishment in prairie reconstructions is considered, much emphasis is placed on the origin and genetic diversity of source materials (e.g., seeds or plugs). However, less emphasis is put on the breeding systems of these plants and how they can affect the long-term persistence of prairie species in prairie reconstructions. Breeding systems refer to the biology of sexual reproduction in plants and as outlined below there is great variety among species. Ignoring the breeding systems of plant species can be detrimental to the reestablishment and preservation of species in these reconstructions. There are two main goals of this section: 1) to summarize what is known about the plant breeding systems of prairie species and 2) to explore how knowledge of breeding systems could be incorporated into prairie reconstruction efforts.

I. PLANT BREEDING SYSTEM OF PRAIRIE SPECIES

A total of 851 plant species have been classified as native to Illinois prairies (8). Although most of the prairies found in Illinois are small and isolated, many still have high levels of plant diversity. It has been estimated that in a 2-to-4-ha (5-to-10-acre) high-quality prairie, approximately 100 to 120 species can be found (8) and recent ongoing studies have documented even higher levels. Information on the natural history and basic biology of these species can range from very comprehensive to nonexistent and data on breeding systems typically are lacking.

An updated literature survey in 2007 on the breeding systems of prairie plants (9, unpublished data) found that although several breeding system studies of temperate plant communities have been conducted (e.g., 10, 11), relatively little information is available on prairie species (but see 12, 13). Determining breeding systems typically involves labor-intensive hand pollination and fruit/seed set determination. The goals of the 2007 survey were: 1) to determine how many species are outcrossers (i.e., xenogamous) vs. self-pollinaters (i.e., autogamous); 2) to identify the compatibility systems of prairie plants (i.e., self-compatible vs. self-incompatible); and 3) to identify prairie species with gender and sexual dimorphisms (e.g., dioecious, gynomonoecious, etc.). Self-compatible species will accept both self and cross pollen, whereas self-incompatible species (obligate outcrossers) will accept only cross pollen from other individuals. A detailed overview of gender and sexual dimorphisms terminology is beyond the scope of this section and has been previously reviewed (14, 15, 16).

During the course of this literature survey, information on 78 prairie species was gathered. If we consider that there are 851 plant species native to prairies in Illinois, then we have published information for only 9% of them! Of course, no single remnant will have all 851 prairie plant species known from Illinois. If a small high-quality prairie remnant can have about 120 or slightly more species, then the picture is not so bleak. Many of the plants for which the breeding systems are known are common, widespread species making the percentage of species for which the breeding system is known in any individual case greater than 9%.

Three conclusions can be made from the available data: 1) 76% to 89% of prairie species can be considered cross-pollinators (i.e., xenogamous) while the rest are self-pollinators (*i.e.*, autogamous); 2) approximately 36% of prairie species are self-incompatible (Fig. 14.2), and 3) about 27% of prairie species have gender and sexual dimorphisms (Fig. 14.3). What is the significance of these results?

a) **Most prairie species are outcrossers:** Studies by Parrish and Bazzaz (12) and Havercamp and Whitney (13) have shown that the great majority of prairie plant species are reproductive outcrossers. Most prairie species are long-lived perennial forbs that as a group tend to be outcrossing species and a positive relationship has been found for many life forms and particular breeding systems (13). In addition, this result points to the fact that most prairie species depend on pollinators for successful reproduction.

b) **Over a third are self-incompatible:** In a study of temperate communities that did not include prairies, self-incompatibility ranged from 27.3% to 85.7% with an overall average of 47% (11). The value for prairie species is lower than what has been found for other temperate communities; nonetheless, this percent could go up if more studies associated with members of the aster family were conducted since these have been known to be largely self-incompatible (15).

c) **Less than a third have gender or sexual dimorphisms:** While gender or sexual dimorphisms are relatively well represented in prairie plants, additional data are needed to determine more precisely the prevalence of these sexual systems. Even so, it can be concluded that most prairie species are hermaphroditic, as has been found for other plant communities (17). In addition, as in other temperate plant communities, the percent of prairie species that are dioecious (i.e., male and female reproductive structures on separate plants [Fig.14.3]) is very low (11, 18).

Additional analyses are needed to determine how the breeding systems of prairie species vary according to life-history traits. For example, the survey conducted by Molano-Flores (9) and updated here does not distinguish whether self-compatibility (SC) or self-incompatibility (SI)

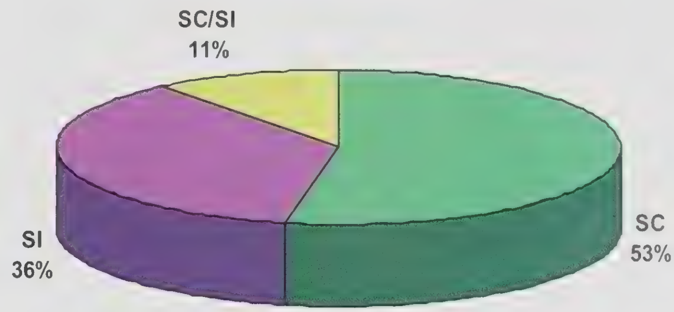

Figure 14.2. Percent of compatibility associated with prairie species. Based on published data for 78 species. SI = self-incompatible, SC = self-compatible, SC/SI = both self-compatible/self-incompatible.

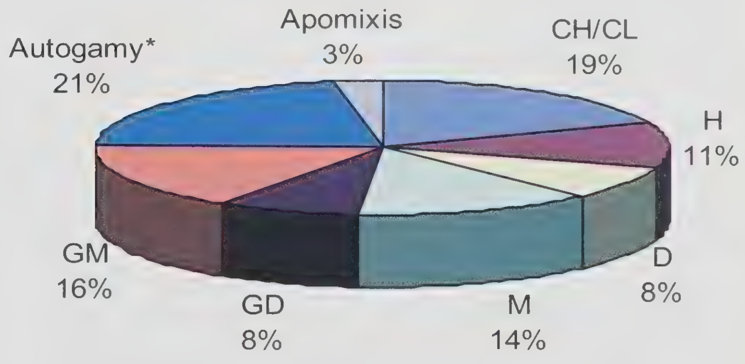

Figure 14.3. Percent of prairie species with each of the following types of breeding systems (based on 37 out of the 78 prairie species with published data): Apomixis = setting seeds without fertilization, Autogamy* = self-pollinated species including chamogamous and cleistogamous species, CH/CL = chamogamous and cleistogamous, D = dioecious, GD = gynodioecious, GM = gynomonoecious, H = heterostyly, and M = monoecious. Percent reported in the text is based on 21 species that have gender/sexual dimorphisms.

is more abundant in grasses or forbs; if there are differences between annual or perennial plants in the proportion of SI vs. SC, or if there are differences among spring, summer, and fall blooming plants for SI vs. SC. These and other questions need to be answered to have a better understanding of how the breeding systems of prairie species compare to plants of other temperate communities. Nonetheless, several predictions can be made. For example, annual prairie species are self-compatible (autogamous) and long-lived perennials should be self-incompatible regardless of pollinator availability.

II) BREEDING SYSTEMS AND PRAIRIE RECONSTRUCTION

While prairie plants have a wide range of breeding systems, when it comes to prairie reconstructions, how can breeding system information be used to assure that plants become established and reproduce successfully? Two main areas where this information is useful are: 1) propagation and 2) reintroduction.

Both sexual and asexual propagation techniques (i.e., seeds, cuttings) are used to develop sources for prairie reconstructions. Nonetheless, many growers ignore the growth form (clonal versus nonclonal species), compatibility system (SI versus SC), and gender/sexual dimorphisms associated with prairie species. This can have detrimental effects on the establishment and reproduction of prairie plants. For prairie species that have a clonal growth form, taking advantage of its asexual reproduction in a propagation program makes perfect sense as it facilitates massive production of a plant. However, the combination of a clonal growth form and self-incompatiblity can lead to no sexual reproduction. This is a valid concern, since research on several clonal self-incompatible prairie species has demonstrated that little to no successful sexual reproduction may occur (e.g., 19, 20). Propagators can take several steps to avoid such issues. For example, identification and labeling of genotypes could reduce the chances that a single genotype is propagated asexually and sold to and planted in a reconstruction. Also, seed collectors can pay attention to how close ramets (independent units of a genetic individual) are to each other to increase the chances of collecting seeds from unrelated individuals in populations of prairie species that are known to be clonal and self-incompatible.

Another example of where propagation techniques can affect the establishment and reproduction of prairie plants is in the case of asexual propagation of plants with gender or sexual dimorphism. In these particular cases, plant populations in prairie reconstructions can end up with a skewed proportion of these gender or sexual dimorphisms. A good example to demonstrate this point is Prairie Willow (*Salix humilis*), one of the few dioecious species in prairies that also has clonal growth. As with many willow species, Prairie Willow can root easily from cuttings and is easy to propagate (21). If cuttings are used without knowing whether they are male or female, individuals in a reconstruction can end up with three potential outcomes: all males, all females, or both males and females. The first two cases, if no other populations are nearby, will lead to no reproductive output other than clonal growth. However, even if both male and female individuals are established in a prairie reconstruction, populations could end up having a skewed proportion of male or female individuals due to planting or asexual reproduction. Proper labeling of cuttings could take care of planting issues, and monitoring (see later section) could determine if populations are skewed to one gender.

Because site reintroductions are done by seeds or plugs, or a combination of seeds and plugs, the best strategy to deal with prairie plants with gender or sexual dimorphisms, is to wait until the plants grow and bloom, determine if potential issues are arising, and then address the problems. As was pointed out with Prairie Willow, having pre-planting knowledge of gender and sexual dimorphisms can inform selection choices and reduce reproduction concerns.

Since the breeding system of a prairie plant can limit its establishment and persistence in a prairie reconstruction, the breeding system should be considered during this process. A proposed four-step strategy can assist in the successful establishment and reproduction of prairie plants by taking into account their breeding systems:

a) **Reconstructions should include multiple seed and/or plug sources:** The goal of this strategy is to obtain seed and plug sources that have genetic variation at the population level. However, the distance from the reconstruction that these sources should come from is a point of debate (22, 23). It has been suggested that these sources should come from as close to the reconstruction as possible. However, molecular work by Gustafson et al. (24) points out that so-called local genotypes should not be given this designation until population genetic work is done, because assuming that geographic proximity will predict genetic relationship among populations could be erroneous.

b) **Seed and plug sources should be kept separate:** Most species-based collections end up being mixed in the end. However, keeping seed and plug sources separated based on their origin will facilitate recognizing any future problems. For example, if the origin of seed and plug sources are well known and documented, establishment, survivorship, and even genetic issues can easily be traced back to the origin of those sources and a recommendation can be made to not collect or propagate from these locations again. Proper documentation of the location of seed sources has been stressed (23). Separation of these sources can be done by either keeping a mix of seeds and plugs from the same location together or keeping each species separate but knowing their origin.

c) **Seed and plug sources of the same origin should be dispersed over multiple areas within the reconstruction:** This will result in the development of a metapopulation (i.e., a group of populations of the same species separated spatially that interact at some level) in the reconstruction. It is important to keep in mind that these seed and plug sources should have enough genetic diversity to avoid

inbreeding depression (i.e., an outcome when offspring have lower fitness due to crosses among related individuals in a population). However, the creation of metapopulations within large-scale reconstructions may also result in outbreeding depression (i.e., an outcome when offspring from crosses between individuals from different populations have lower fitness than offspring from crosses between individuals from the same population). It is a legitimate argument that this approach will be time consuming. And there are those who will feel that it may just be better to have a pre-exiting seed and/or plug mix from different populations and just scatter it about in a reconstruction and let nature take its course to sort out the variation. Although these latter arguments are valid, this approach will fail to benefit from knowledge that could be gained from seed and plug origin in solving not only breeding system issues, but other ecogenetic problems in a reconstruction (see point b).

d) **Monitoring these populations is a must to determine if gender and sexual dimorphisms are present or compatibility issues are occurring:** This is the most crucial point of this strategy as without it, it will fail in its main objective to insure that breeding systems are taken into account during the planning and establishment of prairie plants in reconstructions. Monitoring can be conducted easily by trained volunteers, making it cost effective, as well as educational. Volunteers can be trained to identify species with gender and sexual dimorphisms such as among puccoon species (*Lithospermum* spp.) with their pin and thrum flowers. Pin flowers have short stamens and long styles while thrum flowers have a short style and long stamens; pollination requires crosses between these types, whereas crosses among similar types are ineffective. Volunteers also can be trained to do crosses to determine if compatibility is the main reason for reproductive failure. In addition, the monitoring of these populations is important since sometimes a great portion of whatever is planted as a seed or plug may not survive. This could result in reconstructions having small populations with compatibility issues or populations with skewed gender dimorphisms. For example, Molano-Flores (25) demonstrated that in reconstructed prairies the proportions of pin and thrum flowers for Hoary Puccoon (*Lithospermum canescens*) were skewed to one flower morph, which can lead to lower reproductive success.

In addition, the research opportunities that can be developed by following these steps are tremendous. For example, questions regarding outbreeding vs. inbreeding depression could easily be addressed if the location and origin of seeds and plugs are known. Determining the patterns of gene flow among populations and developing models of extinction and colonization for prairie plant species in reconstructions are also other possibilities. Finally, stability of self-incompatible species, depending on the availability of mates and/or pollinators in these prairie reconstructions, could be examined.

Books, Web pages, and seed and plug providers can easily incorporate breeding system information by simply adding a sentence as part of the species description. Recent publications such as "Prairie Plants of the University of Wisconsin Arboretum" (26) have incorporated this information for some species. For example, in the case of Hoary Puccoon it is mentioned that there are different types of flowers (see pages 137–138), but in the case of Spiked Lobelia (*Lobelia spicata*; see pages 234–235) information on the gender dimorphism found in this species is not explained. Although in a recent publications by the Natural Resources Conservation Services, an excellent job was done describing how to propagate Prairie Willow, no mention was made regarding gender during the propagation process (21). This information is important to the success of prairie reconstructions and should be made available to anyone involved with all aspects of prairie reconstruction. As more and more prairie reconstructions are done by private citizens and public agencies, the incorporation of acquired knowledge will facilitate and ensure the success of these reconstructions. In the past 70 years, a lot has been learned about how to plant prairie reconstructions; however understanding why some species are very successful in prairie reconstructions and others fail to achieve sustainable populations remains in many cases a puzzling question. It can be argued that part of our failure is our lack of understanding of the basic biology of many species, including the breeding systems of prairie plants. For this reason, the more information that is available and incorporated into the process of prairie reconstruction, the more prairie reconstructions will resemble native prairies.

SPECIES LEVEL RECOVERY EFFORTS

Few plant species are geographically restricted (i.e., endemic) to Illinois, mostly due to the absence of factors that lead to geographic isolation. Examples of endemic taxa include Sangamon Phlox (*Phlox pilosa* ssp. *sangamonensis*), a subspecies limited to a narrow reach of the Sangamon River bluffs and adjacent habitats, and Thismia (*Thismia americana*), a diminutive saprophyte of the Chicago Lake Plain prairie that has not been seen since 1916 and is probably now extinct. Decurrent False Aster (*Boltonia decurrens*) apparently evolved in Illinois and is nearly endemic to the state, but also occurs along the Mississippi and Missouri rivers in Missouri. Since most rare species in Illinois have geographic ranges beyond the boundaries of the state, most recovery efforts in Illinois targeting particular species are at the population level. However, for a few species extirpated or nearly extirpated from Illinois, recovery of the species within Illinois, from the perspective of the biodiversity of the state, can be considered species-level efforts. Four species that fall within this category are Lakeside Daisy (*Hymenoxys acaulis* var. *glabra*), Dune Thistle (*Cirsium pitcheri*), Mead's Milkweed (*Asclepias meadii*), and Violet Collinsia (*Collinsia violacea*). These species are highlighted because reintroduction and establishment efforts for these species emphasize different biological aspects of propagation and restoration.

Lakeside Daisy (*Hymenoxys acaulis* var. *glabra*; see Fig. 14.4) is a federally threatened species. This species is a short-lived clonal herb endemic to the Great Lakes region with populations in Illinois, Michigan and Ohio, and Ontario, Canada (27, 28). In Illinois, Lakeside Daisy is known from

Tazewell and Will counties. The population in Tazewell County was the only known inland population for this species and it became extirpated by the late 1940s. In 1981, the last population in Will County was destroyed, but prior to this three individuals were collected in 1979 and maintained in a private garden (27, 29). Although bees (*Bombus* spp.) were observed visiting these individuals, fruits were never formed. DeMauro (29) determined that fruit failure was due to the self-incompatible breeding system, clonal growth form, and low genetic diversity of these individuals. After these factors were recognized and habitat and demographic data were gathered for the Ohio and Canadian populations, a recovery-reintroduction plan was developed (27). In 1988, populations of Lakeside Daisy from Illinois, Ohio and Ontario propagules were reintroduced into prairies at three Illinois nature preserves (Matino, Lockport, and Romeoville). By 1991, survivorship, reproduction, and recruitment varied among sites and it was concluded that these reintroductions were moderately successful (27). It should be noted that, as of 2007, these populations were still surviving at these locations (Marcella DeMauro, pers. comm.). In addition to this reintroduction effort, Ault (30) has developed a micropropagation protocol for Lakeside Daisy using plant tissue culture techniques on shoot tips and stem segments. Because of this modified method of asexual reproduction, additional plants from the Illinois genotype have been successfully propagated, which will allow for the conservation of this germplasm.

Figure 14.4. Lakeside Daisy (*Hymenoxys acaulis*), a federally threatened species that was extirpated from Illinois, at an experimental introduction site in its dry dolomite prairie habitat, Will County, Illinois. Photo by J. Taft.

Dune Thistle (*Cirsium pitcheri*) is a federally threatened species. This species is a short-lived monocarpic (flowers once) perennial plant (Fig. 14.5) globally restricted to dunes of the Great Lakes region in North America. Formerly, this species occurred in Cook and Lake counties in Illinois but habitat loss and degradation eliminated this species from the Illinois shoreline of Lake Michigan by the early 1990s (31). One of the biggest challenges associated with Dune Thistle is its reproductive strategy. As a monocarpic plant, individuals spend most of their life in nonflowering stages. When they reach reproductive age, between three to eight years, they reproduce once, disperse their seeds, and die. Because of this reproductive strategy, the development of stable populations is still a major challenge for this species. Nonetheless, during the 1990s reintroduction efforts were started in remnant dunes along Lake Michigan in Illinois. In 1990, habitat data were collected in Indiana, Wisconsin, and at Illinois Beach State Park to determine the most suitable habitat for Dune Thistle (32). Based on these surveys it was determined that Dune Thistle prefers early and mid-successional blowouts on the high dunes adjacent to Lake Michigan, as these open habitats allow for seedling recruitment. Once the habitat requirements were identified, reintroduction of this species began in 1991at two suitable sites at Illinois Beach State Park. The ultimate goal of this reintroduction is to develop populations that will be stable, increase in size, and will not go extinct in 100 years (31). All the plants that were used in this initial reintroduction effort originated from seed collected in Wisconsin, Indiana, and southwest Michigan and were grown in a greenhouse. From 1998–2000, Bell et al. (33) collected demographic data and developed a demographic model for the species. Based on

Figure 14.5. Dune Thistle (*Cirsium pitcheri*), a federally threatened species, is endemic to the dunes of the Great Lakes. Natural populations have been extirpated in Illinois; however, experimental restoration efforts have restored a small, but potentially unsustainable, population in its native lakeshore dune habitat in Illinois. Photo by J. Taft.

this model it was concluded that the reintroduction of Dune Thistle at Illinois Beach State Park in the short term has been successful since individuals have gone through all the reproductive stages and recruitment has occurred. Although these are encouraging results, Bell et al. (31, 33) have pointed out that the long-term persistence of this species is doubtful unless additional reintroductions are conducted and until enough evidence is available that these populations can endure environmental or demographic stochasticity (unpredictable variation) and disperse to other dunes. As of 2007, a total of 146 dune thistle individuals were found at Illinois Beach State Park (Tim Bell, pers. comm.).

Mead's Milkweed (*Asclepias meadii*) is a federally threatened species. This species, one of 18 milkweed species native to Illinois, is a long-lived clonal prairie herb currently found in small populations in Saline County in southern Illinois on United States Forest Service land (34). The last remaining Illinois population of this species occurring in prairie habitat was destroyed in 2001 (35 [Fig. 4.6]). The recovery and reintroduction efforts in Illinois have included two interesting propagation techniques: 1) germination of seeds from herbarium specimens and 2) plant propagation from clones that no longer produce seeds (32). In 1990, Bowles et al. (32) collected seeds from three Kansas herbaria and tested for germination in 1990 and 1992. These specimens originally were collected in 1987 and 1988 in Kansas. On average 45% of the seeds from herbaria specimens geminated in 1990, very similar to the 47% germination reported from fresh specimens (36). However, no germination occurred in 1992. The seedlings that survived were planted at the Morton Arboretum in Lisle, Illinois. Here a population of Mead's Milkweed from Illinois, Kansas, and Missouri genotypes is being maintained and used for reintroduction purposes (35). As of 1999, this garden population had 60 plants with 30 different genotypes (35). Plant propagation from clones is based on division of adult plants. In addition to this asexual propagation, micropropagation is being developed although no success has been reported (Marlin Bowles pers. comm.). The successful propagation at the Morton Arboretum allows for the use of seeds or seedlings in prairie restoration projects in Illinois, Indiana, and Wisconsin (35, 37, 38). For example, in Illinois Mead's Milkweed has been reintroduced into six sites in DuPage, Ford, Henry, and Will counties (37). As of 2007, these populations were still surviving at these locations (Marlin Bowles, per. comm.).

Violet Collinsia (*Collinsia violacea*) is a state-endangered, small annual species in the figwort family (Fig. 14.6) known from a single population east of the Mississippi River. At this site in Shelby County, Illinois, it occurs in a few local colonies, all within a 1-km radius. These colonies occur primarily in dry-mesic barrenslike habitat associated with bluffs along the west side of the Kaskaskia River. The primary distribution of this species is from Missouri to Kansas and south to Texas; the Illinois population is disjunct from the nearest Missouri population by over 100 miles. How the population became established at this location is an unresolved botanical riddle. It is possible that some animal or even humans were involved in its dispersal. Alternatively, populations may once have linked the Shelby County station to Missouri populations along the Kaskaskia River but became extirpated due to unfavorable conditions such as a missing disturbance factor and/or changing habitat conditions. Sugar Maple (*Acer saccharum*) and other woody understory species appeared to be increasing at this Illinois location and there was concern the trend was a risk factor for the population. To determine what impacts a management fire prescribed to control woody encroachment would have on this lone Illinois population, a field study was conducted. Fire effects on natural communities and species populations can be complex. With regard to annual species, potential effects include leaf litter removal and heat and/or smoke stimulation of the seed bank, particularly in the surface soil horizon. To evaluate these potential effects, fire and leaf-litter removal were used as independent treatments in an experiment (Fig. 14.7). Burn plots had significant increases in mean plant number, compared to baseline, pre-treatment conditions and leaf removal and control (no effect) treatments. With the knowledge that fire likely would do no harm to the population, a prescribed fire was applied to the barrens habitat in the late autumn of 2004, yielding in the following spring the greatest frequency and density of plants observed during the monitoring program.

Figure 14.6. Violet Collinsia (*Collinsia violacea*), a annual species listed as endangered in Illinois, known in the state from only a single population in Shelby County. Photo by J. Taft.

Future management for this population will include periodic prescribed fire to assure persistence of Violet Collinsia in Illinois.

For the successful recovery and reintroduction of these rare species, not only must we understand their natural history and habitat requirements, but we must also develop effective conservation techniques (e.g., tissue culture, long-term seed storage). This will assure that enough specimens are available for the reintroduction of the species into suitable habitat. Finally, species conservation needs to be parallel with community-level restoration and conservation efforts to assure there will be suitable habitats for species recovery.

COMMUNITY-LEVEL RESTORATION

RESTORATION OF OAK WOODLAND AND BARRENS COMMUNITIES

Not only do some species benefit from fire, but several natural communities also rely on fire as a key disturbance factor for structural stability and maintenance of diversity. While the dependence of prairie communities on periodic fire is well established (see Chapter 4), the ecological role of fire in the maintenance and diversity of oak woodland communities is less well known. While there is an extensive past fire history in many plant communities of the Midwest and elsewhere, because of cultural and landscape changes, fire is no longer a frequent occurrence. In order to restore fire-dependent communities, fire often is prescribed as a restoration treatment. This section summarizes results from comparative and experimental fire-effects studies in midwestern oak woodland habitats.

Figure 14.7. Managing a controlled burn in a 1-m^3 aluminum burn box used to replicate fire in an experiment on a population of the state-endangered Violet Collinsia (*Collinsia violacea*) in Shelby County, Illinois. Photo by J. Taft.

Fire conditions are influenced by weather and characteristics of the standing vegetation, fuels, and landscape. Wind speed, humidity, and temperature have a major impact on fire behavior and intensity. Fires spread readily in dry, fine fuels on level terrain. Fires also can readily ascend slopes; however, fire movement down slopes can be slow and riparian or wetland zones can limit fire movement altogether. Natural and created fire breaks can be used to take advantage of such landscape features in designing a controlled burn. To maintain control and assure safety of a habitat management fire, prescribed burns typically are conducted within a set range of these atmospheric conditions. When these conditions don't meet the range set in the burn plan (e.g., winds < 20 mph, humidity > 25% but < 75%, and temperature > 32° F), typically the burn is postponed. Although during a prescribed burn conditions can change suddenly out of prescription, prescribed burns usually are conducted under conditions that allow the greatest control (39) and not under conditions that, while possibly more effective at achieving management goals, are more difficult to keep within the limits of the planned burn unit (potentially leading to unwanted conflicts). The result of prescribed burns typically is quite different from tree-crowning wild fires that can occur in, for example, conifer forests of the southeastern or western U.S. or in California chaparral. In prescribed midwestern woodland burns conducted within prescription, flame heights in early stages of restoration seldom exceed a meter (Fig. 14.8) and typically can be characterized as slow-moving ground fires. Exceptions are where flames occasionally ascend a dead tree. Once woodlands are opened up, ground-layer fuels increase and air movement is greater, flame height, intensity, and ecological effects can be expected to increase.

The goals of fire management typically are to address issues relating to species diversity and compositional and structural stability of the natural community. To gauge progress and test hypotheses about fire effects, trends in several community-level parameters such as species richness, diversity, composition, and structure can be monitored (40). Examining the effects of fire in terms of species-response types, survival mechanisms, physiognomic group response, and analysis of biodiversity trends lead to better understanding of how fire affects community structure and organization. Fire effects in woodland vegetation can differ among the vegetation layers with the magnitude of the effect tending to increase not only with fire frequency but also from overstory to shrub/sapling and finally the ground-layer vegetation where the most prominent effect is often found. To distinguish effects of fire treatment, it is important not only to monitor vegetation in burn units but also in nearby untreated reference areas of the same habitat. Such monitoring allows treatment effects to be distinguished from

Figure 14.8. Typical low flame height in a closed woodland late-dormant season burn. Beaver Dam State Park, Macoupin County, Illinois. Photo by J. Taft.

general ambient trends. These results, particularly those from long-term studies that exceed transient (short-term) responses, can lead to better predictions about fire effects and the capacity of restoration activities that rely on prescribed fire. Characteristic fire effects on each vegetation layer are described below.

Tree Stratum

The effects of fire on trees is of particular interest because among the most salient consequences of long periods of fire absence in oak woodlands has been increasing tree density and consequent shading of ground layer vegetation (41, 42). Summarizing fire effects on the overstory of oak woodlands is confounded by the fact that the overstory of oak woodlands can span from a condition of relatively stable composition and structure to unstable (the typical condition), with many examples suggesting ongoing changes. Under typical conditions where moisture or nutrients are not strongly limiting to forest development, increasing tree density often is among non-oak species (e.g., Figs. 4.36, 4.47). In contrast, sites on dry and nutrient-poor sites demonstrate primarily structural changes, or instability, because species of more mesic habitats tend to be absent or are intolerant of dry site conditions. In structurally unstable dry upland habitats such as barrens or sand savannas, the problem can be too much oak regeneration leading to a closed stand and a shaded and increasingly sparse ground-layer. In addition to sources of variation based on levels of stand stability, fire intensity can vary widely from mild, to moderate, and intense (usually associated with unplanned wildfires) with increasing effects on stem density. One intense fire can mimic the effects of multiple moderate burns (43).

Single burns implemented within prescription typically have negligible effects on tree species composition and total basal area, and often only slight effects on tree density. Stem mortality from fire is caused when heat is transferred through bark, killing cells of the vascular cambium, a meristem (cell production zone) responsible for secondary (i.e., diameter) growth in trees. This temperature threshold has been reported to be around 60 °C (140 °F) and characteristics of the bark, particularly thickness as well as properties of thermal conductance, regulate rate and intensity of heat transfer (44, 45). Other factors include fire residency time. A slow-moving fire increases residency time, allowing heat to penetrate further into a stem. Thick-barked species are slow to heat and slow to cool once heated, while thin-barked species experience more rapid temperature changes (46). In general, stem survival is highly correlated to bark thickness (47). However, should injury occur to the vascular cambium, stem death may not be immediate; consequently, a full assessment of mortality sometimes can not be made in a monitoring program until two or three years following a burn. Variation in recovery from cambial injury relates to the effectiveness of a tree's defense response in compartmentalizing the damaged area and limiting secondary effects of fungal decay pathogens (48).

In contrast to the short-term and limited effects of a single burn, comparative and longer-term studies have shown that as the number of burns increases, so too do the effects on tree density (Fig. 14.9), with a 26% to 30% reduction in stem numbers with three to four burns after initially little change. Similar results were found in a Missouri oak-pine woodland (49). However, effects on tree density mostly are confined to the smallest size classes (Fig. 14.10). Increasing fire frequency has the effect of reducing greater numbers of small trees until under conditions of high fire frequency (i.e., annual burns) most are eliminated (e.g., 50) eventually leading to a unimodal tree size-class distribution (Fig. 14.11) and an open woodland structure (Fig. 4.49). However, because small trees contribute little to stand basal area (the sum of tree cross-section area at breast height [4.5 ft]), the basal area can be slow to change (51), or actually increase slightly over time with fire (52, 53) despite significant decline in tree density. This is because the large trees contribute the majority of basal area in a stand and continue to increase in diameter, thus compensating for the loss of basal area of eliminated small trees. Larger trees tend to have greater thickness of protective bark (47), so they tolerate fires, particularly those typical of prescribed burns, with little or no demonstrable effect for many species. However, species richness tends to decline gradually as fire-intolerant species (e.g., small tree species and those with thin bark) selectively are reduced.

Proportionately greater mortality with fire for particular species suggests some are more sensitive to fire than others (e.g., Hackberry [*Celtis occidentalis*], Redbud [*Cercis canadensis*], Persimmon [*Diospyros virginiana*], Red Mulberry [*Morus rubra*], Sassafras [*Sassafras albidum*], and Slippery Elm [*Ulmus rubra*]). Most of these tend to be small trees with the majority of stems in the smaller diameter classes and thus they are more vulnerable. However, in one

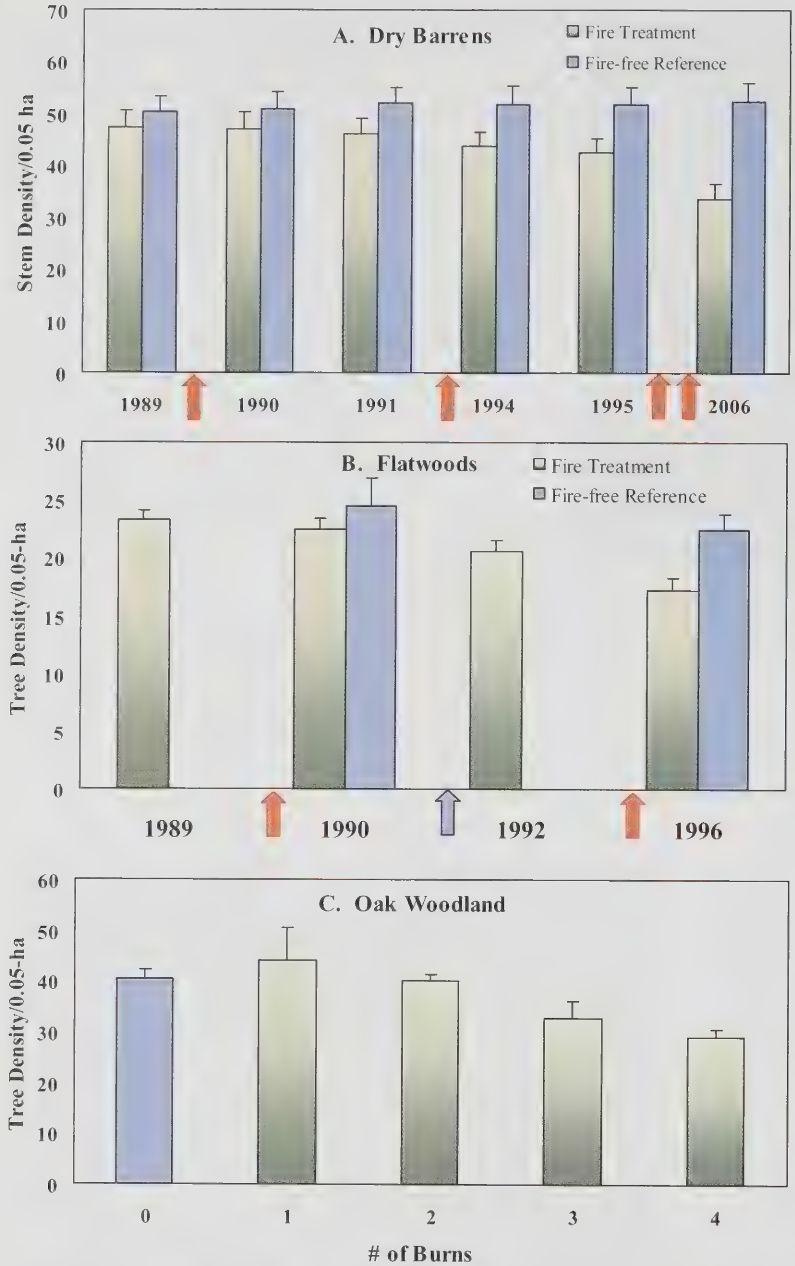

Figure 14.9. Changes in tree density showing trends with fires in A) dry barrens and B) flatwoods, and C) comparing tree density in oak woodlands burned with up to four fire events. Red arrows indicate effective burns; blue arrow indicates a relatively cool, low intensity, fire event.

study, several large specimens of Mockernut Hickory (*Carya tomentosa*), a species considered extremely susceptible to fire (54), were killed following three burns (53). Tree species can be categorized according to their response to fire (51). Fire-tolerant species can persist either by *resisting* heat damage (e.g., thick bark) or *endure* fire by readily resprouting. Fire-intolerant species often are killed by flames, and so are successful by *avoiding* fire. This latter group includes the mesophytic (plants of mesic habitats) invaders in oak woodland habitats such as Sugar Maple. These avoid fire by occurring in ecological niches where fire tended (in the former time) to be infrequent; however, many have spread beyond these habitats during long periods of fire absence. Sugar Maple perhaps is the most characteristic of mesophytic tree species that have become commonplace in the subcanopy of oak woodlands in the Midwest (55, 56).

Eliminating all shade-tolerant trees that invade oak woodlands during periods of fire absence can not always be accomplished with prescribed fire alone (51, 57). Among 12 tree species in an oak-dominated flatwoods community, only Sugar Maple had no decline in numbers following three burns (53). There appears to be a feed-back mechanism that allows persistence of some fire-intolerant species even with the return of fire to the system (57, 58). For example, beneath Sugar Maples there often is low fuel loading, a result of intensive shading and relatively light-weight leaves which readily decompose or blow away. Without fuel for fire, little heat damage is imparted to cambial tissues.

Successful oak regeneration requires the coincidental timing of the occasional acorn mast year with seedling recruitment opportunities. The greatest benefits have been found with a moderate recent fire history (e.g., three to four burns) while annual burning consistently has been detrimental to oak seedling regeneration (59). Seed predators and browsing animals would need either to be low in numbers or be saturated with resources (i.e., lots of acorns) for successful seedling and sapling establishment. Once a stand is opened up with three to four burns and shade levels reduced, a temporary hold on fire management likely would be needed to provide an opportunity for seedling and sapling development to yield a new cohort of replacement oak trees. All factors need to be integrated when managing for the persistence of oak in woodland habitats.

Shrub and Sapling Stratum

The shrub-sapling stratum is the immediate recruitment pool for future trees and as defined in many of the cited burn studies here includes woody stems < 5 cm dbh and greater than 50 cm in height. This understory stratum can be quite dynamic in terms of changes in stem density per area with, and sometimes without, fire. While recently burned units tend to have lower density of stems in the shrub-sapling stratum (Fig. 14.12A), there can be variation depending on differences in species composition. Where species that endure fire by resprouting are common (e.g., Sassafras and Black Raspberries), fire can actually cause a dramatic increase in stem density (Fig. 14.12B). Otherwise, the effects of fire typically result in a rapid reduction in stem density followed by recovery towards baseline condition until next burn (Fig. 14.12C). Under both latter circumstances, stem increase/decrease was strongly correlated to baseline stem density. The more stems the greater the increase or reduction with fire.

Comparison of fire treatment plots to fire-free reference plots in a long-term study in dry barrens habitat shows that in the absence of fire there can be an undulating pattern caused by recruitment of stems into (from seedlings) and out of (stems reach tree size class) the shrub-sapling

stratum. Surprisingly, coincidental to the pattern of response to fire, there was a convergence to similar structure in burned and unburned barrens habitat after many years of monitoring and four burns in the fire-treatment vegetation (Fig. 14.12A), suggesting that under intermediate fire frequencies, the effects on shrubs and saplings can be transient unless prolific sprouting species are abundant. With high fire frequency (every year or two), the effects are greater and can strongly reduce total stem density and species richness (50, 60).

A measurement of percent similarity between tree species in the subcanopy and canopy strata provides a means to assess compositional stability and patterns of overstory regeneration. At sites where compositional stability is low due to mesophytic invaders, it can take many years of monitoring and a temporary cessation in a fire management program to determine whether conditions have improved adequately for regeneration of dominant overstory species such as oaks.

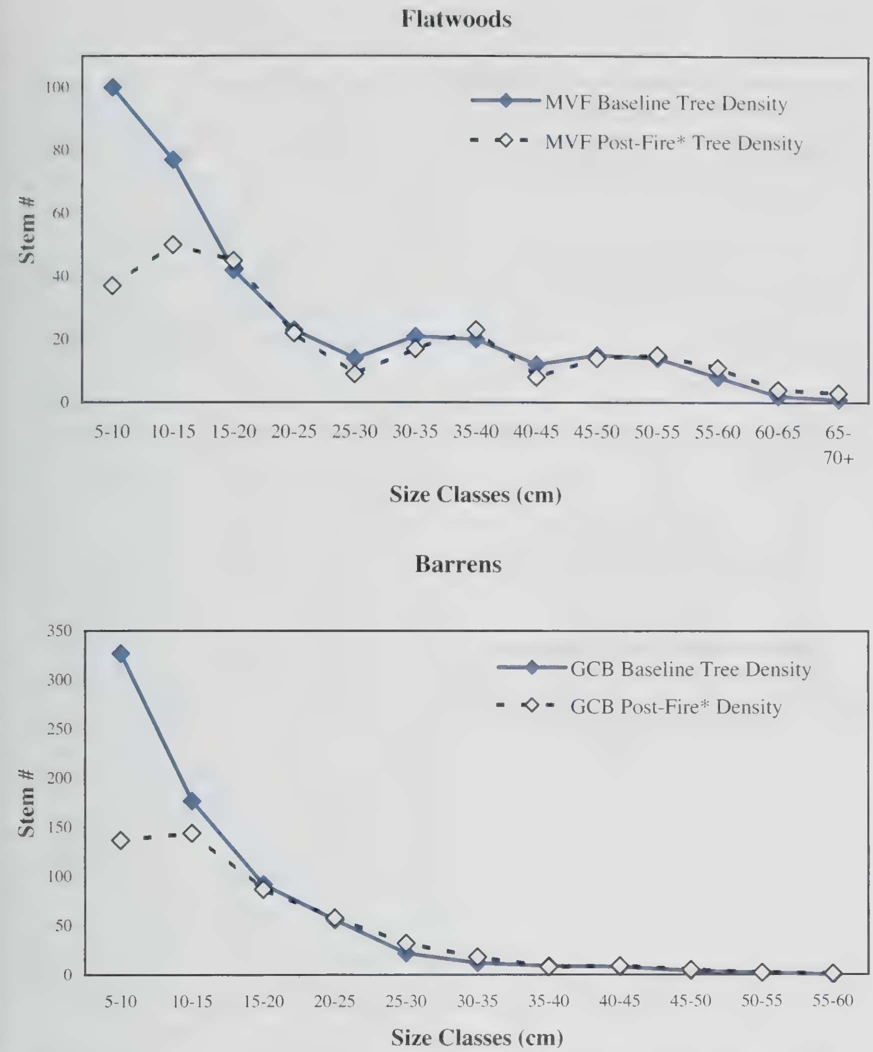

Figure 14.10. Comparison of the distribution of tree size-classes before (baseline) and after prescribed fire treatments (MVF * n = 3, GCB* n = 4). MVF is Mount Vernon Flatwoods (53) and GCB is Gibbons Creek Barrens (52). Total sample area in both studies was 0.75 ha.

Ground-layer Response to Fire Management

In oak woodland and savanna habitats of Illinois and the Midwest, the greatest floristic diversity is in the predominately herbaceous ground-layer vegetation. Species found in this stratum are a mix from prairie, savanna, and woodland habitats including grasses (often including both warm and cool-season species), sedges, a great variety of forbs, herbaceous and woody vines, low shrubs, and tree seedlings. There are influences of the overstory on ground-layer vegetation as well as influences of the ground-layer on the overstory (61) and fire has a direct effect on these reciprocal interactions. Cover and composition in the herbaceous ground-layer have been found to influence tree seedling recruitment patterns (62, 63, 64). One of the major effects of the overstory on ground-layer vegetation is by intercepting sunlight. Due to shade intolerance for many ground-layer species (particularly species from prairie and savanna habitats), fire absence ultimately limits ground layer diversity and percent cover. As with accumulations of duff in prairies (65), leaf litter

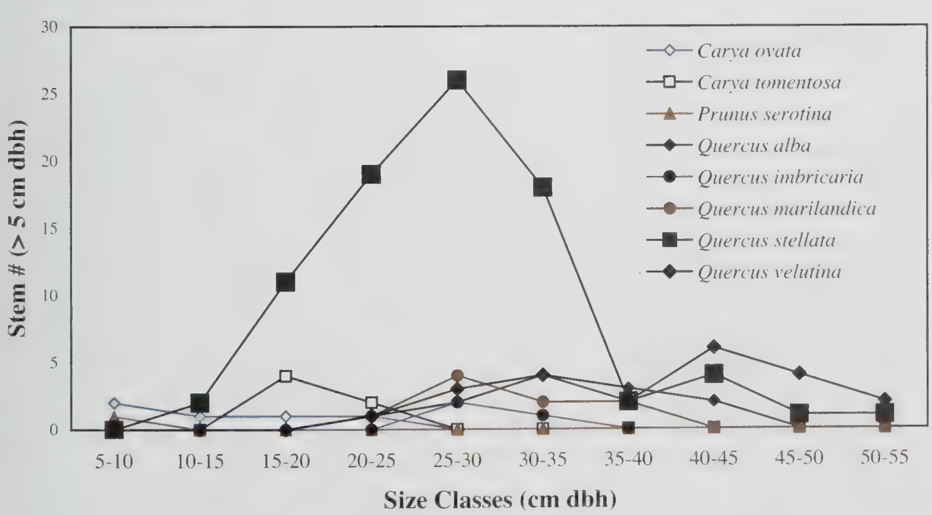

Figure 14.11. Size-class distribution for trees at a flatwoods in Effingham County following a 20-year period of frequent (nearly annual) fire.

accumulation in woodlands as stands close also can have a smothering effect on herbaceous species and limit seedling recruitment opportunities. This attrition in the ground layer can be seen in some long-term monitoring studies with untreated reference vegetation and the signal pattern is an inverse correlation between overstory tree density and ground layer diversity (42). Sometimes a threshold can be seen in tree density where the attrition effect begins and this provides a management benchmark for targeting tree density reduction (66). Where this attrition pattern exists can serve as a signal for restoration potential. There are two possible explanations when no such correlation exists within a site: either shade levels have yet to exert an influence on patterns of ground-layer diversity, or there has been full attrition of shade intolerant species and the remaining flora is indifferent to shade levels, a common circumstance in midwestern woodland habitats. One of the goals of fire management is to affect this interaction by reducing tree density and consuming the build up of leaf litter improving niches for seedling recruitment for herbaceous ground-layer species (67, 68).

In results from monitoring studies examining fire effects in flatwoods and barrens habitats, following three-to-four dormant season fires, species density (richness of ground-layer species per quadrat) increased two-to-three fold compared to baseline levels. The responses follow a step-wise pattern of increase after each fire followed by gradual decline (Fig. 14.13). In oak woodland habitat at Beaver Dam State Park, the density of ground-layer species was twice that in a management unit with three previous burns compared to other management units with little or no recent fire history (Fig. 14.14). In another comparative study in flatwoods, one site with a recent 20-year history of frequent fire (Fig. 4.49) had species density more than four times that of unburned sites and weedy species were absent (60). Similar patterns of increase in species richness have been found in woodland burn studies elsewhere in the Midwest (43, 50).

In the monitoring studies described above, overall population sizes increased for most herbaceous species in burn units (fire increasers greater in number than fire decreaser or no-change taxa) and the proportion of infrequent species (prone to local extinction) declined (52, 53). In contrast, in fire-free reference units, diversity trends downward (Fig. 14.13A) with the exception of very sparse and densely shaded understories where tree seedlings and woody vines can make up a majority of the diversity (e.g., Fig. 14.13B). Similar to effects on species richness, fire also resulted in greater percent cover of ground-layer

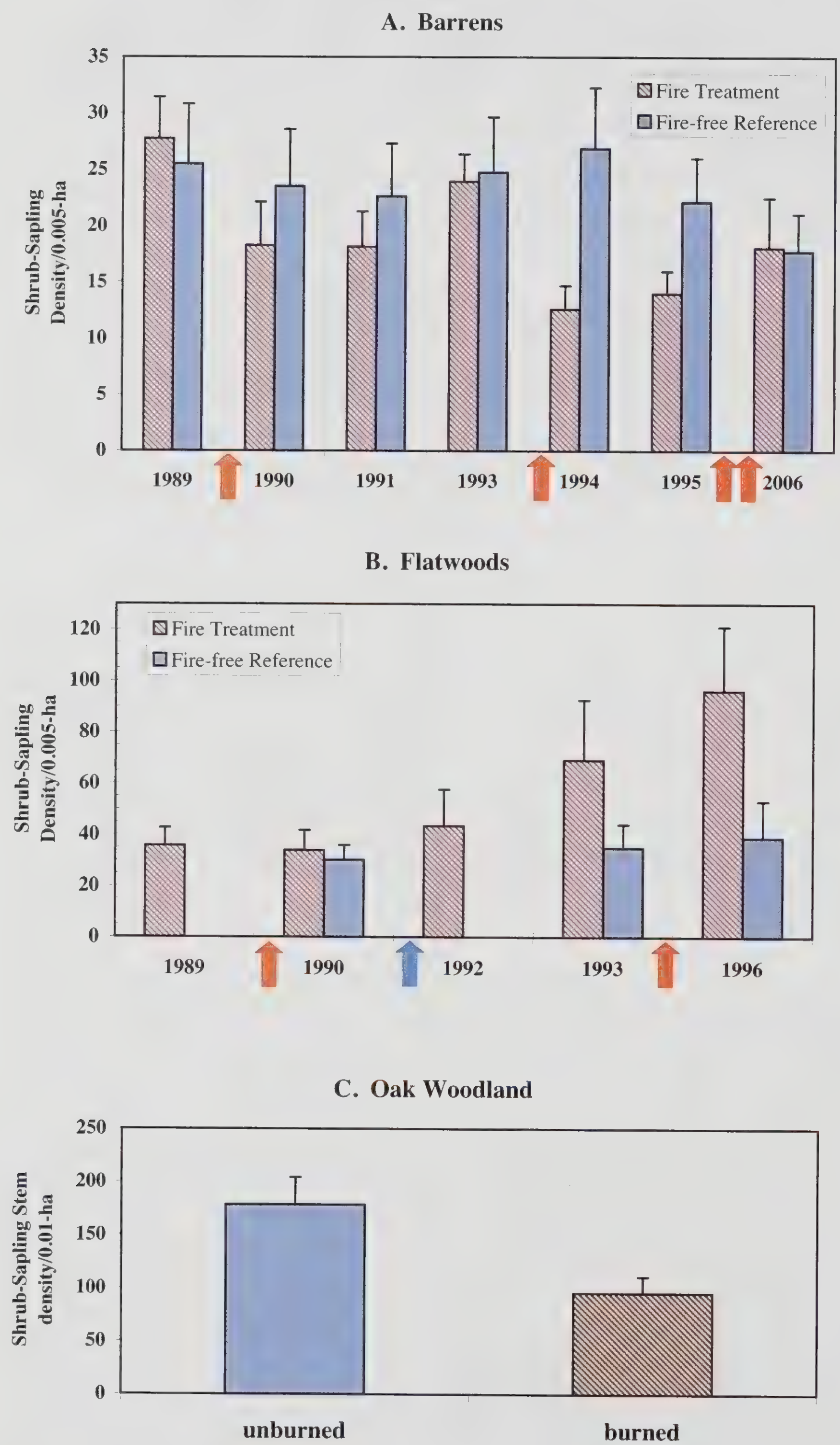

Figure 14.12. Changes in shrub/sapling density showing trends with fires in A) dry barrens and B) flatwoods, and C) comparing shrub/sapling density in unburned and burned oak woodlands. Red arrows indicate effective burns; blue arrow indicates a cool-fire event.

vegetation and less bare ground. These differences between fire-treated and unburned sites highlight not only the role of fire in maintaining diversity but also the gradual decline of species from unburned and increasingly shaded sites. Since the vast majority of oak woodland sites do not receive fire treatment, a general trend throughout oak woodland habitats appears to be a gradual loss of diversity of herbaceous species.

Much of the increase in species richness at burned sites emerges from the soil seed bank. Seed dormancy can be broken in a variety of ways including, particularly for thick-coated seeds, heat from fire (69). Seeds near the soil surface are stimulated by heat and/or smoke to germinate. In recent years, volatilized compounds in smoke have been recognized as having a direct effect on germination for many species in the seed bank (70, 71). Some seed may be too deeply buried to receive stimulation while seeds at the surface or in the leaf litter may be consumed by fire (45), including acorns (72). The viable seed bank provides an important refuge for diversity during periods of unfavorable environmental conditions, particularly in highly fragmented landscapes where the opportunity for species immigration needed to compensate for species losses is strongly limited (73). One of the ways fires may promote diversity is through a mosaic of fire intensities that stimulate seeds at different soil depths. Due to fuel patchiness, open woodland and savanna habitats can be expected to have heterogeneous fire responses.

While the seed bank of isolated habitat fragments has promise for restoration potential, the composition of the seed bank can reveal the warts of site history. For example, after three burns in an isolated old-growth flatwoods remnant bordered by pasture, a sharp increase in ground-cover diversity (Fig. 14.13B) included not only characteristic flatwoods species (e.g., numerous sedge and forb species appropriate for the habitat) but also a proliferation of native weeds such as White Snakeroot (*Eupatorium rugosum*) and Pokeweed (*Phytolacca americana*) that were absent prior to fire management (53). These latter taxa are not typical of undegraded flatwoods and probably reflect a history of livestock grazing or substantial seed inputs from adjacent pastured lands. Longer-term studies in such habitats are needed to determine whether these species are perpetuated indefinitely by burning or eventually are displaced by competition from other emerging native species. While perennial forb and sedge species increased greatly in frequency and richness, only a single native perennial grass emerged following fire treatments. Perennial grasses are a major component of flatwoods when not densely shaded (60). In such situations, species introductions may be needed to restore the full complement of plant functional groups.

PLANT FUNCTIONAL GROUPS

Plant functional groups are categories of species with shared attributes and may be based on traits such as morphological or physiological characteristics, life history, ecological roles, resource use, or response to disturbance (74). Examples include annual and perennial forbs, warm-season grasses, cool-season grasses, herbaceous and woody vines, hemi-parasites, and nitrogen fixers (e.g., legumes and actinorhizal plants). Changes in these categories can provide insights into fire effects on community structure, diversity, and ecosystem function. Increasing fire frequency during the dormant season tends to result in an increase in grasses and a decline in woody species. Annual species often show a dramatic increase immediately after fire and return to preburn levels within a year post fire (52). Perennial forbs showed the greatest increase in diversity and total percent cover with fire management in barrens habitat (Fig.14.15a), while these groups declined in the same habitat without fire (Fig. 14.15b). While perennial grasses often increase with fire (65), responses can differ among cool-season and warm-season cohorts (Fig. 14.16). For cool-season species, trends with fire are a decline in percent cover the year following fire treatment, despite increases in frequency, followed by a dramatic increase in percent cover the following year.

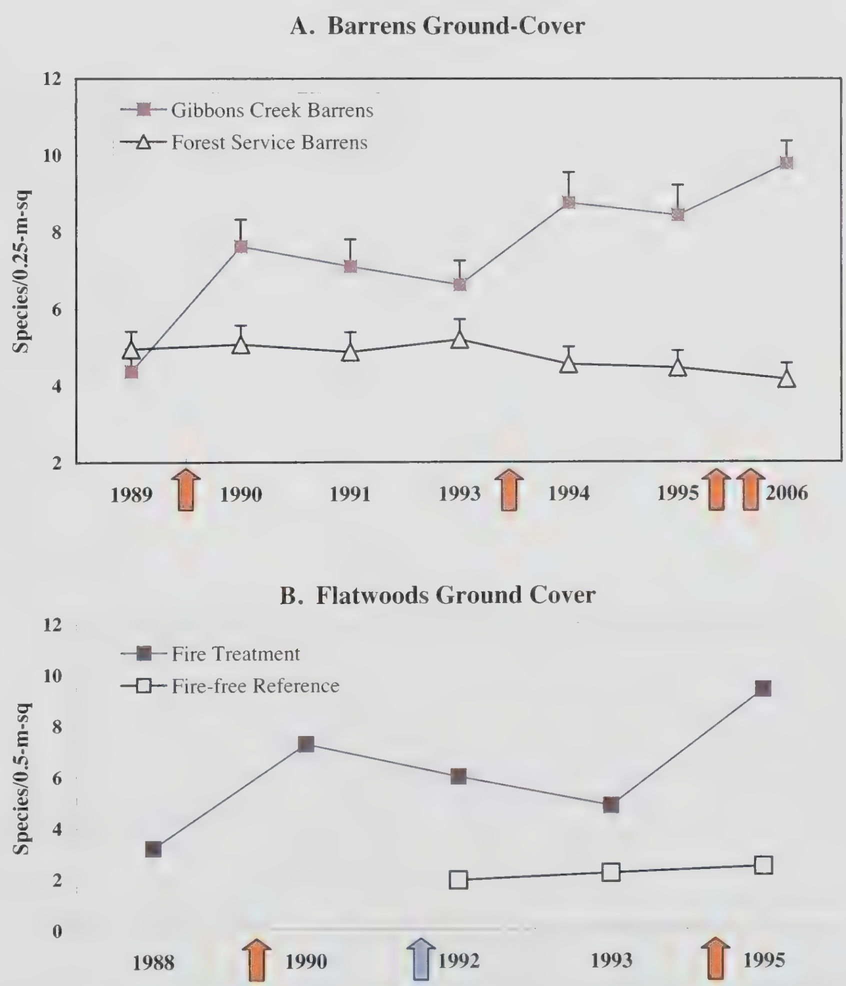

Figure 14.13. Trends in ground-layer species density in A) dry barrens and B) southern flatwoods communities with fire comparing treatment and fire-free reference vegetation.

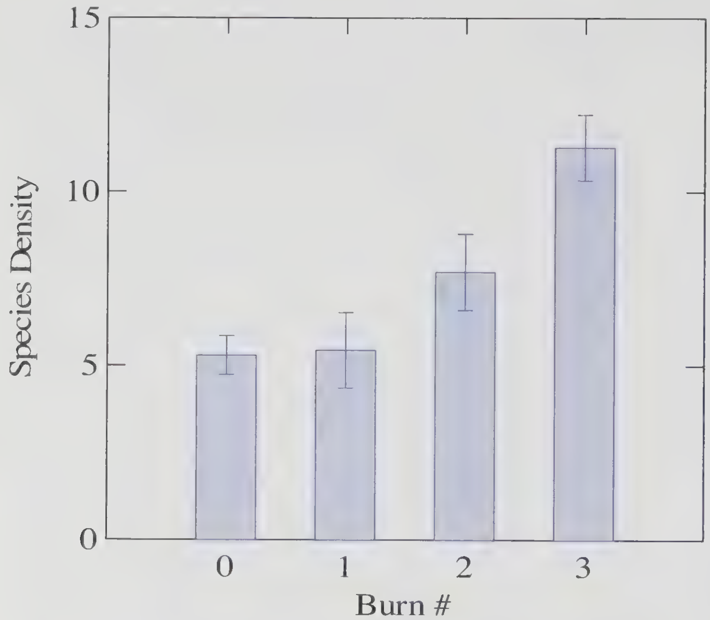

Figure 14.14. Differences in ground-layer species density in oak woodland habitat comparing unburned and units burned up to three times. Error bars indicate standard error.

Warm-season prairie grasses are a major component of many savanna and barrens habitats and because of their intolerance to shade, trends can provide a benchmark, a sort of mine-shaft canary, for habitat conditions. Despite the first two management fires in a dry barrens where Little Bluestem *(Schizachyrium scoparium)* was the dominant species (52), trends in total abundance were downward and for several years parallel with trends in unburned reference vegetation (Fig. 14.17). This was true despite a reduction in overstory tree density in the treatment site (Fig. 14.9). Following two more burns, totaling 4 in 17 years, the decline in frequency for Little Bluestem in fire-treatment vegetation appears to have been halted and there was an upturn in percent cover in the latest sample while the decline continued unabated in fire-free reference vegetation (Fig. 14.17). Not only has percent cover of Little Bluestem declined from 12.5% to 3.5% at the reference site, but frequency also declined from 35% to 15%, indicating the reduction in cover is in part due to plant losses that will be difficult to reverse. In contrast to Little Bluestem, panic grasses and sedges (*Dichanthelium* and *Carex* spp.) typically found in open woodlands and barrens habitats increased dramatically following each fire, emerging from the soil seed bank. Similar findings have been found in Ohio studies (43, 75, 76). Evidently, Little Bluestem does not persist in the soil seed bank, suggesting targeted management efforts that reduce overstory tree density will be needed to sustain populations.

Most fire effects studies in oak woodlands and savanna habitats of the Midwest have been conducted in the past 20 years, so it is a relatively young field of research and there remain many opportunities to gain important insights. In particular, more study is needed on effects of fire season on vegetation structure and seed bank dynamics, different plant community responses to fire, and the role of fire-return intervals on regeneration of overstory species, particularly oaks. Given the brevity of study, additional long-term studies of fire effects on structure, composition, and diversity of all biota also are needed for a more comprehensive understanding of fire effects following long fire-free intervals. There is great urgency given the perspective (57) that time may be running out on the potential for fire to be an effective management tool for the restoration of oak woodland habitats.

FOREST RESTORATION PRACTICES

The transition from woodland to forest is a gradual continuum, and determining where woodland ends and forest begins requires some rather arbitrary criteria. While consensus has been lacking on precisely defining this transition, when canopy cover exceeds 80%, stands often are classified as forest (Fig. 4.19). Reference points and goals for forest restoration in Illinois are variable depending on site objectives. On public lands and many private stands, the restoration reference point is the perceived condition prior to European settlement when species of oak and hickory were particularly dominant in upland forests (see Chapter 4 Introduction for discussion regarding use of the

Figure 14.15. Ground-layer plant functional groups in A) fire treated (Gibbons Creek Barrens, burn n = 4) and B) unburned (Forest Service Barrens) dry barrens comparing baseline and post-treatment data.

presettlement time frame as a reference point). However, most of the research and observations relevant to forest restoration in Illinois has been in silviculture, a forestry discipline that emphasizes natural and artificial regeneration of forests with a focus on commercial timber species. Less effort has been devoted to restoration of shrub and small tree species that find their niche in the forest understory or to the flora and fauna of the forest floor. This includes the unique vernal flora of spring wildflowers found only in temperate deciduous forests. The term restoration in its broad sense also can include the establishment of forests where none currently exist, alteration of forest structure, restoration of ecosystem function, or alteration of forest composition. Examples of the latter method would be native plantings and forest stand improvement involving the promotion of native species of plants and associated fauna with the elimination of invasive exotic plants.

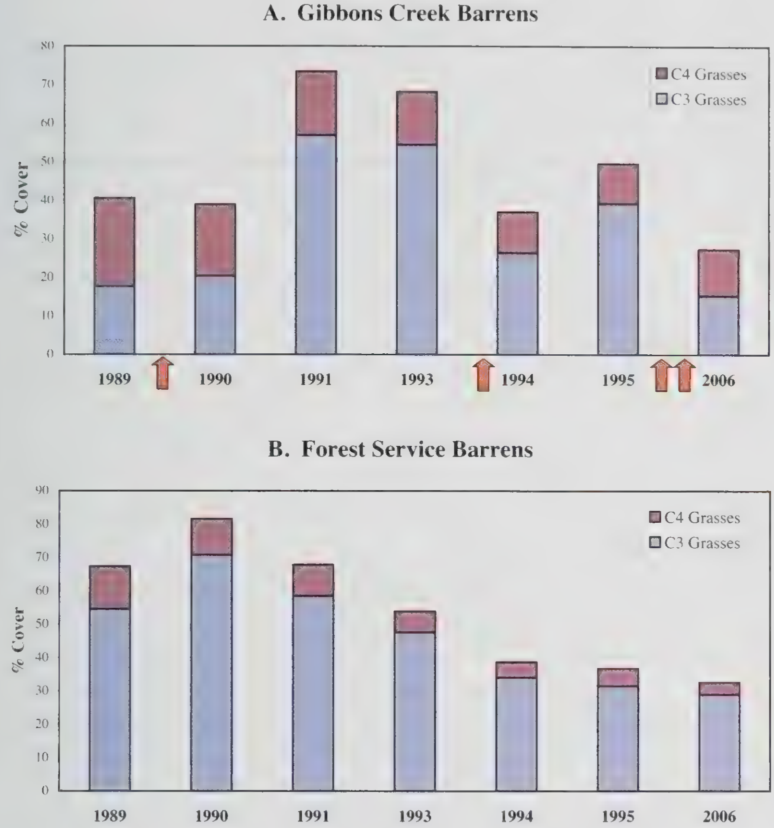

Figure 14.16. Trends among warm-season (C4) and cool-season (C3) grasses in A) burned (Gibbons Creek Barrens; burns = 4) and B) unburned (Forest Service Barrens) dry barrens. Red arrows indicate times of fire treatments.

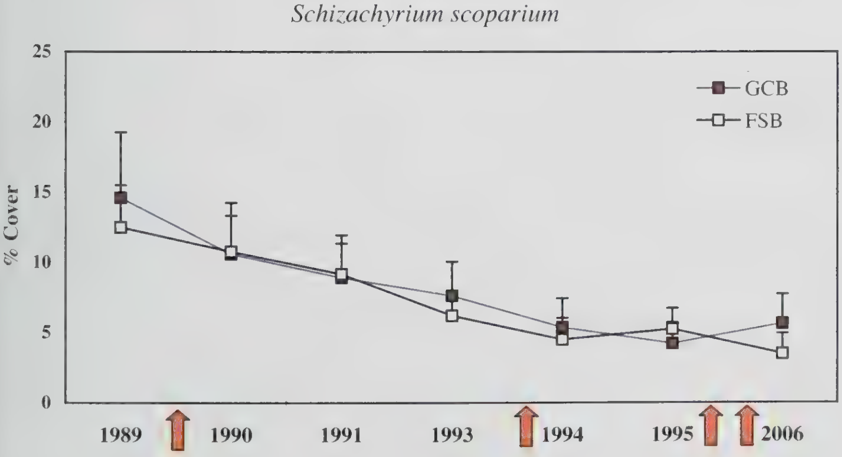

Figure 14.17. Trends in percent cover for Little Bluestem (*Schizachyrium scoparium*), a warm-season (C4) grass, in burned (GCB) and unburned (FSB) dry barrens.

Different approaches will be required for the restoration, enrichment, or re-establishment of the many forest types found in Illinois, some of which are uncommon and scattered throughout the state. Examples of the diverse forest types in Illinois include Larch (*Larix laricina*) forests in bogs in northeastern Illinois, local White Pine (*Pinus strobus*) stands in northern counties, swamps in the south with Bald Cypress (*Taxodium distichum*) and Tupelo (*Nyssa aquatica*), southern floodplain forests with Sweetgum (*Liquidambar styraciflua*) and bottomland oaks, beech-maple forests of eastern and southern counties, rich cove forests in highly dissected terrain, and many others (some discussed previously in Chapter 4). As noted previously, many of these forest types exist today as fragments isolated from their original association with tallgrass prairie, savanna, and a mix of other forest types, all in a mosaic influenced, in ways we have yet to fully understand, by fire, storms of ice and wind, activities of indigenous tribes, and the impact of large herbivores such as Bison and Elk. Upland oak forests will be the focus of this section.

With the alterations in the former disturbance regimes, as with savanna, barrens, and woodland habitats previously described, changes have been underway in forest composition and structure and a conversion of oak-hickory dominance to dominance by other species, particularly Sugar Maple, elms, and Black Cherry (*Prunus serotina*), is well underway. Such tree species are termed "tolerant" because of their ability to regenerate in shaded forest understories. Seedlings and especially saplings of shade intolerant species such as oaks cannot become established or survive in stands with a closed canopy (e.g., > 80%). This trend towards increasing abundance of tolerant tree species has even acquired the somewhat sinister name of "maple takeover" (77). Maple groves in presettlement times were localized in sites protected from fires by watercourses and topography. Since then the widespread trend towards Sugar Maple dominance, particularly in subcanopy strata of forest preserves (e.g., Fig. 4.36), is most probably a result of reduced fire, reduced logging, and elimination of herbivory by large mammals (e.g., Elk) that favored oak.

Today, many old second-growth forests that retain oak dominance in the overstory can be traced to extensive logging after the

Civil War that provided railroad ties and other building materials for the expansion of railroads westward across the treeless Great Plains. Oaks probably regenerated from existing seedlings and saplings established under open forest canopies, or as a result of the successful seeding of oaks from residual trees bordering openings. Many young oak forests of today occur in former pastures and other fields abandoned decades ago and grazed lightly, if at all, in the intervening time period. These associations of oak dominance to past disturbances provide clues to ecological factors that influence forest development and provide the ecological basis for forest management and restoration. For example, oaks and hickories have selective advantages for invading open prairie compared to other tree species. The heavier seeds of oaks and hickories more readily penetrate grassland thatch compared to the lighter seeds of maples and elms. They also have sufficient energy reserves to produce shoots and roots that can compete with other vegetation for light and soil resources after germination and initial growth. Conditions for acorn germination can be improved with prescribed fire by increasing contact with mineral soils and reducing shade levels (78). Additionally, oak seedlings can survive repeated fire and browsing better than seedlings of other species owing to their development over time of a thick main root. This "lignotuber" contains sufficient energy reserves for rapid regrowth of sprouts after periodic destruction of shoots by fire or browsing. So, oaks and hickories have adaptations to former conditions in the prairie-forest transition zone (79).

It is also important in restoring forest communities to recognize the effects of modern anthropogenic factors. From the forest interface with human dwellings and communities up to the landscape level, urban development continues to impact the structure, composition, and function of our native forests. Fragmentation of upland forests into isolated stands surrounded by housing developments results in reduced opportunities for the types of forest management practices that would sustain forest integrity. For example, the ability to use fire, hunting, aerial spraying, and other silvicultural methods to manage forests, their wildlife populations, and devastating insect and disease infestations is diminished with increased urbanization. Forest habitat in urban areas also can foster deer overpopulation, resulting in starvation as well as harm to forest wildflowers and tree regeneration. Altered hydrology in riparian forests in urban areas, including increased and prolonged flooding, has led to declining tree species diversity and increasing dominance of Silver Maple, a species that germinates readily on bare mineral soil.

Forests along rivers, streams and associated wetlands in Illinois are subject to frequent, periodic disturbance from flooding. Regeneration patterns in these ecosystems are complex and often linked with hydrological cycles as in the case of seed release of riparian tree species such as Sycamore (*Platanus occidentalis*), Green Ash (*Fraxinus pennsylvanica* var. *subintegerrima*), and Cottonwood (*Populus deltoides*) in concert with spring flooding and deposition on fresh deposits of sand and silt. Paintings by early explorers of the Wabash River reveal forests of tilted and leaning Sycamore, Green Ash and other species along the stream banks strikingly similar to forests found there today. Notwithstanding major hydrological changes, this frequently disturbed ecosystem, with continual damage to and uprooting of established trees by flooding and water-born debris, apparently retains some of its pre-settlement character today even under added human impact. Restoration efforts in floodplain and wetland forests in the Cache River bottoms of southern Illinois show that light-seeded species such as Green Ash and Sweet Gum (*Liquidambar styraciflua*) regenerate naturally in large numbers relative to planted wetland forest species such as Bald Cypress (*Taxodium distichum*) and flood tolerant native bottomland oaks. There is a need to focus research efforts on regenerating diverse native wetland tree species in concert with altered or restored hydrological processes and both natural and reconstructed features of floodplain micro-topography.

THE CLEARCUTTING METHOD FOR NATURAL REGENERATION OF OAK

Clearcutting is a major disturbance to forest stands often opposed by the public and associated with profiteering by timber companies. However, irrespective of the commercial possibilities, clearcutting can enhance opportunities for oak regeneration by dramatically increasing available light, vital for shade-intolerant species. In this way, clearcutting emulates the occasional severe disturbances that once were part of the natural processes such as a severe fire or storm event. The clearcutting method, however, does not automatically ensure regeneration of forests containing oak and associated tree species. The method can best be used to regenerate oak-dominated stands only when the amount of oak advance regeneration and potential for oak and hickory sprouting, especially from small diameter seedlings and saplings, is adequate to replace the stand (~500 stems per acre). Advance regeneration of oaks is likely to prevail only in stands with open canopies, especially on dry sites where tree regeneration is restricted to a limited number of drought-tolerant species such as several oaks. On more productive sites with closed canopies including rich coves and stands on north-facing slopes, the advance regeneration may be a diverse mixture of species and include mostly shade-tolerant trees such as Sugar Maple. In this situation clearcutting will only accelerate change to Sugar Maple-dominated forests and will not yield an oak-dominated forest.

In stands with limited opportunities for oak regeneration, burning that does not kill dominant trees and open the forest canopy by about one-third to one-half usually does not allow sufficient light to reach the forest floor to allow establishment and survival of oak and other, less shade-tolerant, species. Burning does, however, improve light penetration by temporarily removing the understory layer of small trees that reduce light penetration to the forest floor and by creating a better seed bed for oak germination, a result of litter removal resulting in earlier soil warming and better soil/seed contact. Burning also can favor seedlings and saplings of oaks and hickories, species that readily resprout after fire, compared with nonsprouting species such as elms and Sugar Maples. Nonetheless, these benefits of prescribed burning by themselves, without treatments that greatly reduce the overstory canopy, will seldom successfully regenerate oak-dominated forests. The minimum size

commonly prescribed for a clearcut is two acres. Stands smaller than two acres have a large proportion of their area in the border zone where light levels, soil nutrients, and water are attenuated because of competition from surrounding trees. In this border zone reproduction grows slowly. Ideally, clearcuts can be arranged and situated so they mingle with uncut stands and blend into the landscape as much as possible. By a common definition of a clearcut, all large trees are removed and smaller trees greater than two inches in diameter at breast height (DBH) are cut or killed. Killing some large trees and letting them stand instead of cutting and removing them will provide nesting holes and perches for wildlife. Throughout Illinois, upland stands will commonly contain White Oak (*Quercus alba*), Black Oak (*Quercus velutina*), Northern Red Oak (*Quercus rubra*), hickories (*Carya* spp.), White Ash (*Fraxinus americana*), Black Cherry, and other tree species, with a greater variety occurring on deeper, moister, more productive soils. In eastern and southern Illinois on mesic sites, the new stands may also contain Yellow Poplar (*Liriodendron tulipifera*) and American Beech (*Fagus grandifolia*). On the drier sites the new stands can be strongly oak-dominated when they reach 15 to 20 years of age.

THE SHELTERWOOD METHOD FOR NATURAL REGENERATION OF OAK

If there is not enough advanced oak reproduction to replace the stand, the shelterwood method can be effective in regenerating oak. In the shelterwood method for regenerating forests, 30% to 50% of the canopy may be removed to allow enough light to reach the forest floor to support seedlings of low- to mid-tolerant species of tree. Inadequate oak advance reproduction that can be addressed by the shelterwood method is most likely to occur on the middle and lower north- and east-facing slopes. These are cooler and moister than other slope aspects. The shelterwood method can be used for either natural oak reproduction or for underplanting oak seedlings. Research to design shelterwood methods that will consistently reproduce oaks successfully is incomplete. A prescription based on current knowledge indicates that it is first necessary to control the understory that will compete with the small oaks to be regenerated from seeds of trees left after initial cutting. Understory trees and shrubs are controlled by cutting, burning, or killing (with approved herbicides) the unwanted species up to about two inches d.b.h. The overstory is then reduced to about 70% of full stocking. A fully stocked stand is one in which all the growing space is occupied. Stocking tables for stands of a given density (number of stems per unit land area) and basal area (the total cross-sectional area of the tree trunks on the site per unit land area) are available from Cooperative Extension, Natural Resources Conservation Service, and Illinois Department of Natural Resources foresters. The desired dominants (trees above average stand height) and codominants (trees at average stand height) should be as uniformly spaced as possible in a shelterwood removal. Seedling establishment and growth should be monitored and additional light overstory cuts should be prescribed if adequate regeneration of desired tree species does not occur within five years. Understory trees and shrubs should be removed again if they redevelop to a point where they restrict the growth of oak reproduction.

THE SINGLE TREE SELECTION METHOD

This method is not recommended for reproducing oaks, though it is used successfully for selective logging of maple forests without greatly changing the forest structure or composition. This is because shade-tolerant maples reproduce prolifically and are self sustaining. This method emulates the small gaps created by natural mortality of individual trees in mature stands of forests that quickly are filled by advance regeneration of the same tolerant dominants. While this method is commonly employed in a variety of upland forests for timber extraction, it gradually reduces the number of oaks in the overstory and creates conditions that are more favorable for reproducing and releasing seedlings and saplings of shade-tolerant tree species in the forest understory. The few small oak seedlings that might occur in closed-canopy forest must compete with larger and more numerous seedlings of shade-tolerant species established in the understory. This competition does not favor the oak seedlings that are usually not able to grow into the main canopy under a single tree selection method.

The single tree selection method has been widely employed in timber harvesting because it does not radically change the appearance of forests and it typically focuses on removal of only the few scattered trees of the highest quality and value, those being the large, columnar, and defect-free individuals that can be sliced into thousands of square feet of wood veneer. The selection method does not tempt economically-motivated landowners to convert forest land to agricultural uses as do methods involving more drastic tree removal. For this reason, forestry advisors and consultants might prescribe this method to optimize short-term economic return without greatly altering forest aesthetics. Understandable as this approach might be, in the long run it can lead to the elimination of oak forests, which may be more valuable as wildlife habitat, a source of commercial timber, icons of natural heritage, and as reservoirs of biotic diversity (80).

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CHAPTER 15

A Finger on the Pulse of Illinois Forests— Early Results of the Critical Trends Assessment Program

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OBJECTIVES

The monitoring component of the Critical Trends Assessment Program was designed to answer questions about ecological conditions and changes in forests, grasslands, wetlands, and streams across Illinois. This chapter presents results from statewide forest plant communities, focusing on baseline or ambient forest conditions, changes in stands over a five-year interval, and a comparison of ambient forests to the region's highest quality reference stands.

Additional CTAP data on birds and terrestrial insects in random and reference forest, wetland, and grassland sites are also collected as well as data on benthic macro invertebrates from random and reference stream segments. More information pertaining to these other habitats can be viewed on the CTAP Web site (http://ctap.inhs.uiuc.edu) and in (1, 2).

INTRODUCTION

Throughout the history of Illinois, forests have provided generous resources to generations of inhabitants. In the early 1800s Illinois forests, woodlands, and savannas totaled approximately 15.3 million acres (see Chapter 4). Since Euro-American colonization beginning in 1820-30s, wood resources were in high demand during this time, resulting in extensive clearing of forests. By 1923 only 3 million acres of forest remained, mostly second-growth (3). Since that time, reforestation programs and changes in land use have helped to restore Illinois forest and woodland areas to the current total of 4.5 million acres. Like most land in Illinois, the majority of this timberland is privately owned with approximately 169,000 individuals owning 3.7 million acres, leaving 795,000 acres in public ownership (see Chapter 4). The once extensive tracts of woodland and forest have become very fragmented with 63% of all parcels less than 100 acres in size (see Fig. 4.35 in Chapter 4). Of the original forested acreage in Illinois, only 16,452 acres are known to remain in high-quality (little disturbed) condition (see Chapter 4). The majority of these areas are now protected in parks or preserves.

The Critical Trends Assessment Program (CTAP) was established in 1992 as a means to inform land managers, stewards, and policy makers about the conditions of Illinois' ecosystems. In 1997, field methodologies were developed to begin long-term monitoring of Illinois forests, wetlands, grasslands, and streams. Within each habitat, permanent study areas have been established in randomly selected locations across the state. Information is recorded on the vegetation, bird, and insect communities at each terrestrial site, and aquatic insect (macroinvertebrate) information at each stream site. Sites are revisited every five years to detect and assess changes that occur within each of these communities.

By the end of 2006, permanent plots had been established in 154 random forest stands. As a reference for comparison, 23 additional sample localities were established in forests recognized as high-quality representatives of their type by the Illinois Natural Areas Inventory [INAI] (5). A wide range of forest communities from upland forests (Fig. 15.1A) to floodplain forests (Fig. 15.1B) was sampled. These sites encompass 9 of the 14 recognized forest types in Illinois based on the INAI community classification (Table 15.1).

Plant data at each CTAP site are collected from three different layers of vegetation: the ground cover, shrub/sapling (including woody vines), and tree/canopy layers. In addition, a complete species list is recorded from a standard sample area at each study site. CTAP calculates several indices to measure conditions and changes in the plant communities. The main indices discussed in this article include those related to measuring species richness, species dominance, importance value, and Floristic Quality Assessment. Definitions for these and additional terms referenced in this chapter are listed in Table 15.2. For more explanation on the CTAP Program and details on monitoring methods refer to Molano-Flores (6), Chapter 3 of this publication, or the CTAP Web site http://ctap.inhs.uiuc.edu.

As mentioned previously, the majority of land in Illinois, including forested land (see Fig. 4.28 in Chapter 4), is privately owned. This is exemplified in the randomly selected CTAP forest sites of which 77% are privately owned (individuals or organizations), compared to only 18% of reference sites being privately owned.

Nearly all the CTAP random forests have experienced historic and/or current disturbance with logging

Figure. 15.1. A) Randomly selected upland forest site in Winnebago Co., IL. The large canopy trees are Red and White Oak (*Quercus rubra* and *Q. alba*) but the understory and shrub layer is almost entirely Sugar Maple (*Acer saccharum*). B) Randomly selected floodplain forest site in Randolph Co., IL which, as typical, shows a thick ground layer of Wood Nettle (*Laportea canadensis*) and a sparse shrub layer. Photos by CTAP staff.

Table 15.1. Types of forest communities sampled for the monitoring phase of the Critical Trends Assessment Program.

Natural Community*	# of Sites
Random Forests	
Dry-mesic upland forest	80
Wet-mesic floodplain forest	23
Mesic floodplain forest	20
Mesic upland forest	18
Wet floodplain forest	6
Dry upland forest	2
Dry sand forest	2
Dry-mesic sand forest	2
Tree plantation	1
Reference Forests	
Dry-mesic upland forest	12
Wet-mesic floodplain forest	9
Mesic upland forest	2
TOTAL	177

* Communities base on (10).

and grazing being the most common. The intensity of disturbance has ranged from minor to extreme. However, most stands have not experienced grazing by domestic livestock or timbering in several decades and the majority of the random CTAP forests stands are estimated at 40 to 80 years of age. Reference forest stands have experienced very little human disturbance in their known history and several are considered remnant old-growth stands. Trees at these sites average between 100–200 or more years of age. These random and reference forest sites represent a wide range of forest conditions in Illinois, from those that have been recently logged or storm damaged to nature preserves that have remained relatively undisturbed since the time of European settlement.

FOREST COMPOSITION AND STRUCTURE—RESULTS FROM THE FIRST TWO MONITORING CYCLES

By the close of the second monitoring cycle (2002–2006), 129 of the random sites had been revisited for a second round of data collection. The majority of comparisons in this section focuses on data summaries from these 129 random forest sites and the 23 reference forests, using the most recent second-cycle data from the random forests. A single five-year cycle is a relatively short time period to track changes in long-lived species such as trees, but for certain aspects of forest dynamics (e.g., non-native invasions in the herb layer), such a time frame is sufficient for discerning notable changes. Accordingly, most of the CTAP forests did not show substantial changes in species number, composition, or community characteristics between the first and second visits, except for a few apparent trends (see FOREST CHANGES section).

Most CTAP forests are dominated by species native to Illinois, which comprise about 93% of the species composition in random forests and 95% in reference forests. This is in sharp contrast with CTAP grassland and wetland habitats across the state, habitats that often are dominated by non-native species (7, 8). Despite the predominance of native species, most CTAP random forests (93%) also harbor at least one non-native plant species (Table 15.3) and, more importantly, nearly 87% harbor at least one problem invasive species, an indication of potential threats to future species composition in Illinois forest communities (Table 15.3). Although about half of the approximately 339 species listed as threatened or endangered by the Illinois Endangered Species Protection Board occur in forest habitats (see Chapter 4, Forest Section), as a testament to their scarcity only a single occurrence of one species, Northern Grape Fern (*Botrychium multifidum*), has been found in CTAP random forest sample plots. Only two listed species, Bloodleaf (*Iresine rhizomatosa*) and Storax (*Styrax americana*), each a single occurrence, have been found in the reference forest sample plots.

CTAP random forests averaged greater richness of both native and introduced (non-native) species per site compared to reference forests, while the reference stands averaged a slightly higher number of sensitive and threatened and endangered species (Fig. 15.2). However, measurements

Table 15.2. Definitions of terms that are used as indicators of terrestrial habitat health.

Bioindicator	Description
Basal area	The cross-section area of a tree trunk, based on DBH measurements
Coefficient of Conservatism (CC)	An assigned value (Taft et al. 1997) to denote a species' tendency to only be found in pristine, unaltered natural areas; in other words, how weedy is the plant? Values range from 0 -10 [very weedy – highly conservative]
Density	The number of stems per unit area
Diameter at Breast Height (DBH)	The diameter of a tree at 4.5 ft (1.3 meters) above ground level
Disturbance tolerant species	Species with a CC value of 2 or less
Dominance (species dominance)	Species that has the greatest Importance Value of all species on a site, in each vegetation layer
Floristic Quality Assessment (FQA)	The process of incorporating the Coefficient of Conservatism (CC) and the Floristic Quality Index (FQI) toward evaluating the natural condition of an area
Floristic Quality Index (FQI)	Measures the conservation value and habitat quality of a plant community in a given area using CC and species richness (11)
Frequency (species frequency)	The number/percentage of plots or sites where a species is present
Importance Value	Importance Value is a measure of the relative proportion and relative frequency that each species occupies within a specific area. Calculated by summing data such as as relative frequency, relative coverage, relative density, and (for trees) relative basal area for each species.
Introduced or Non-native species	Species that originated from outside of Illinois or the United States
Native species	Species that are indigenous to Illinois
Problem species	Species that is a known management problem based on the Illinois Nature Preserve Management Handbook (Illinois Nature Preserves Commission 2005)
Sensitive species (Conservative)	Any species with a CC value of 7 or greater
Species richness	Number of different species in a given area
T & E species	Any species that is State or Federally Threatened or Endangered

Table 15.3. Total number of CTAP forest sites where sensitive, threatened (T) and endangered (E), introduced, and problem plant species were sampled. Also included is the number of sites where native and introduced species were dominant in the ground cover and shrub layers.

	CTAP Random Forests				CTAP Reference Forests	
	First Visit (129 sites)		Second Visit (129 sites)		23 sites	
Criteria	# sites	% of total	# sites	% of total	# sites	% of total
At least one sensitive species	70	54.3	68	52.7	15	65.2
At least one T&E species	1	0.8	0	0.0	2	8.7
At least one introduced species	106	82.2	120	93.0	16	69.6
At least one problem species	107	82.9	112	86.8	12	52.2
Ground cover layer						
dominated by native species	114	88.4	112	86.8	22	95.7
dominated by introduced species	15	11.6	17	13.2	1	4.3
Shrub layer						
dominated by native species	126	81.8	94	72.9	22	95.7
dominated by introduced species	28	18.2	35	27.1	1	4.3

of conservation value and habitat quality (Floristic Quality Index and average Coefficient of Conservatism [see Table 15.2]) varied only slightly between random and reference forest stands (Fig. 15.3).

FOREST PLANT COMPOSITION

The next few sections of this chapter discuss the major species represented within each of the separate vegetation layers found in a forest ecosystem (canopy, shrub/sapling, ground layer) based on their dominance within that layer. For the purpose of this chapter, dominance refers to the species that have the greatest calculated importance value within each vegetation layer. Importance value incorporates values of density, frequency, basal area, etc. of each species relative to the other species within a specified area. This use of the term dominance strays somewhat from the tradition forestry use which pertains mainly to the tree species with the greatest relative basal area (cross-section coverage) in the canopy layer (see Table 15.2 for definitions).

FOREST CANOPY

Among trees, dominance was shared by many species in both random and reference stands. Pooling information across all random CTAP forests, American Elm (*Ulmus americana*) was revealed to be the most dominant species because of

its high frequency and density. It was found to occur in 62.5% of the tree plots at 82.2% of the sites. American Elm occurred with an average density of 73.3 stems per hectare (2.47 acres), far greater than most other species. The majority of these trees, however, occurred in the smaller size classes with American Elm having an average diameter at breast height (DBH) of 13.5 cm and average basal area (see Table 15.2) of 1.3 meters^2/hectare. As a result, on an individual site basis, American Elm only dominated a small proportion of the sites where it occurred (6.2%). White Oak (*Quercus alba*) ranked second in importance, but with very different circumstances. It occurred in 37.5% of the plots on 52.7% of the sites. Density at 29.4 stems of White Oak per hectare is quite a bit lower than for American Elm, but the average basal area of 3.5 meters^2/hectare and DBH of 38.1 cm indicate that the majority of these trees occur in the larger size classes (see Fig. 15.4 for size-class distribution pattern for trees). White Oak was the dominant species at 14.7% of the random forest sites, about half the sites where it was recorded. Sugar Maple (*Acer saccharum*), ranking sixth in overall importance, was not found as commonly as American Elm, but tended to be present in greater numbers where it

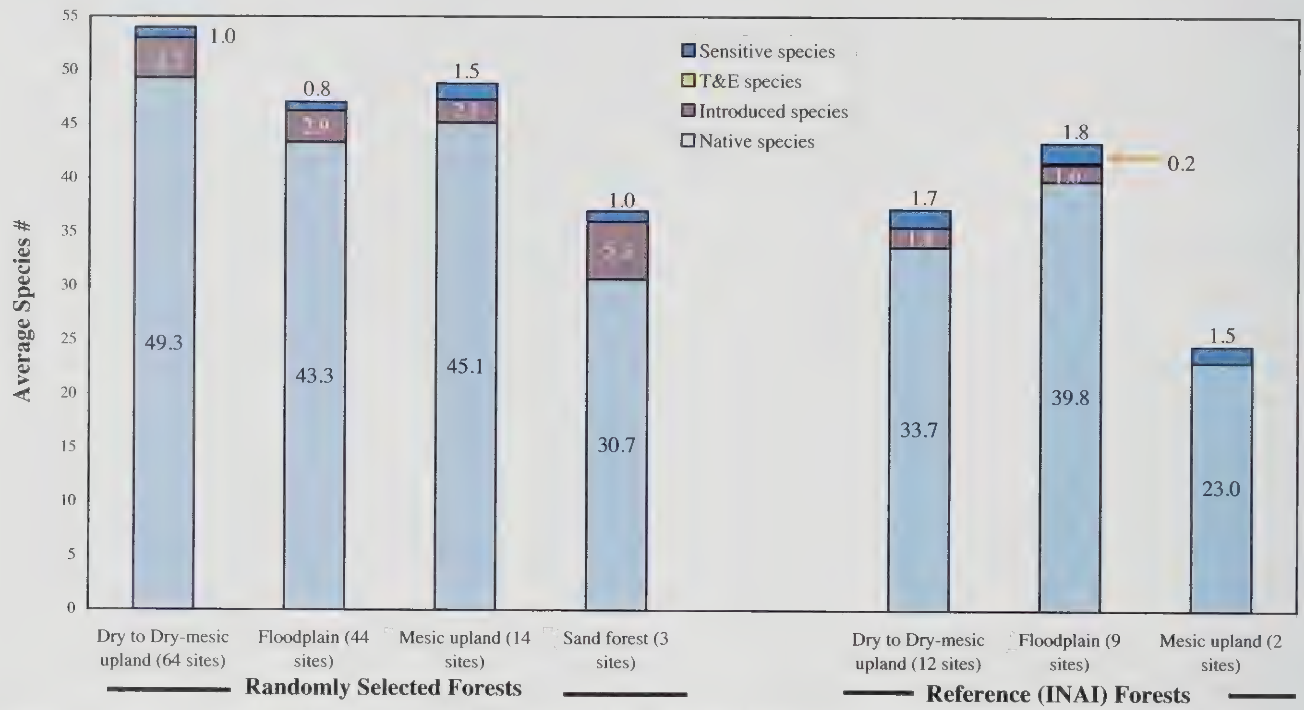

Figure 15.2. Average number of plant species in CTAP random and reference forests by community type; data shown are from the second vegetation sample cycle.

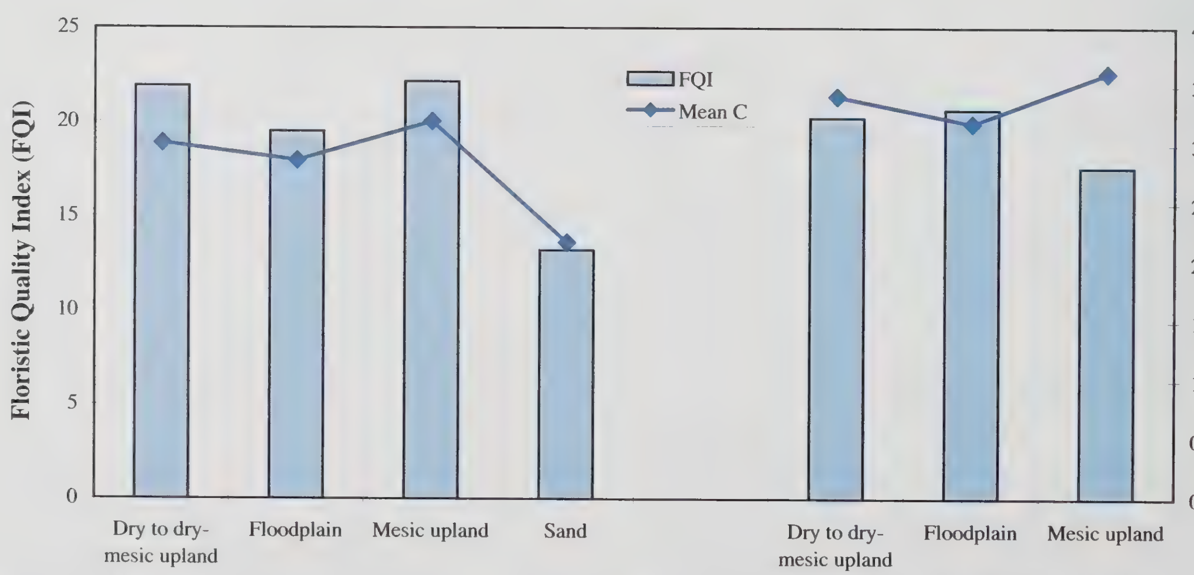

Figure 15.3. Average floristic quality values from sample data in CTAP random and reference forest communities (sample cycle 2). The Floristic Quality Index (FQI) and average Coefficient of Conservatism (Mean C) are defined in Table 15.2.

did occur. Sugar Maple, considered a problem invasive species at many reference forests where it ranks as the most important tree species (see below), is not yet problematic at most CTAP random forests. Sugar Maple was present in substantial numbers (average density of 49.8 per hectare) but was recorded in only 24% of the plots on 30.2% of the random sites. It dominated the canopy at 11.6% of the stands where it occurred. A basal area of 1.1 meters^2/hectare and an average DBH of 13.7 indicate that, similar to American Elm, Sugar Maple is present mainly in the small size classes (Fig. 15.4).

Data from CTAP reference forests (Table 15.4) indicate that, in contrast to random forests, Sugar Maple is the most dominant species followed by White Oak and Slippery Elm (*Ulmus rubra*). Sugar Maple occurred in about half the tree plots, with just over 100 stems per hectare and average basal area of 3.5 meters^2/hectare. White Oak ranks second in overall importance. It occurs in only 39% of tree plots with relatively low density compared to other dominant species but with basal area of 6.6 meters sq. per hectare, much greater than any other species in either random or reference stands.

While there are differences in rank order of importance for tree species, more notable are the structural differences between random and reference forest stands. The randomly selected forests have much greater overall density of trees compared with older-growth reference stands, averaging 737 trees per hectare (Table 15.5) compared to about 533 trees per hectare at reference stands. This is true especially among the small to intermediate size classes, while reference stands have more large trees (Fig. 15.5). In contrast, reference stands have average basal area of 34.6 meters^2/hectare compared to 27.3 meters^2/hectare at random forest stands. A key difference is the greater proportion of basal area in CTAP random forests contained in the small-to-intermediate size classes while the older-growth reference sites have substantially more basal area in the larger size classes (Fig. 15.6).

Patterns of stand replacement described previously in Chapter 4 (Forest Section) that are characterized by poor oak regeneration and an increase in species like Sugar Maple and elms in smaller size classes are readily apparent in CTAP dry to dry-mesic reference sites (Fig. 15.7). In contrast, data from CTAP random dry to dry-mesic forest stands illustrate a substantially different tree composition and structure. In these younger, more recently disturbed forests, oaks are the most prevalent species across all sites with oaks and hickories more evenly distributed among all the tree size classes (Fig. 15.4). Elms, followed by hickories and Sugar Maples, were the most prevalent species in the smallest classes. As time increases since canopy-opening disturbances, we expect that the proportion of oaks in the smaller size classes will decline as these forests become more shaded and less suited to oak regeneration. The tree species compositions will most likely gradually shift over time to resemble those of the reference forests unless additional disturbances (e.g., selective logging or multiple burns) occur that reopen the canopy and make conditions more favorable to oak regeneation.

SHRUB/SAPLING AND WOODY VINE LAYER

Virginia Creeper (*Parthenocissus quinquefolia*), a shade-tolerant woody vine that frequently ascends tree trunks, was the most commonly encountered species in the shrub/sapling layer of random forest stands, occurring at 73.6% of sites. However, the non-native Multiflora Rose (*Rosa multiflora*) was the most dominant species overall in the shrub layer. Multiflora Rose occurred on 53.5% of the random sites, dominating 12.4% of them, with an average density of 515.8 stems per hectare (Table 15.5).

At CTAP reference forest stands, Spicebush (*Lindera benzoin*) was the overall dominant shrub due to its high density. Sugar Maple, although occurring in much lower overall density compared with Spicebush, was the dominant species at 48% of the sites, far more than any other species (Table 15.4).

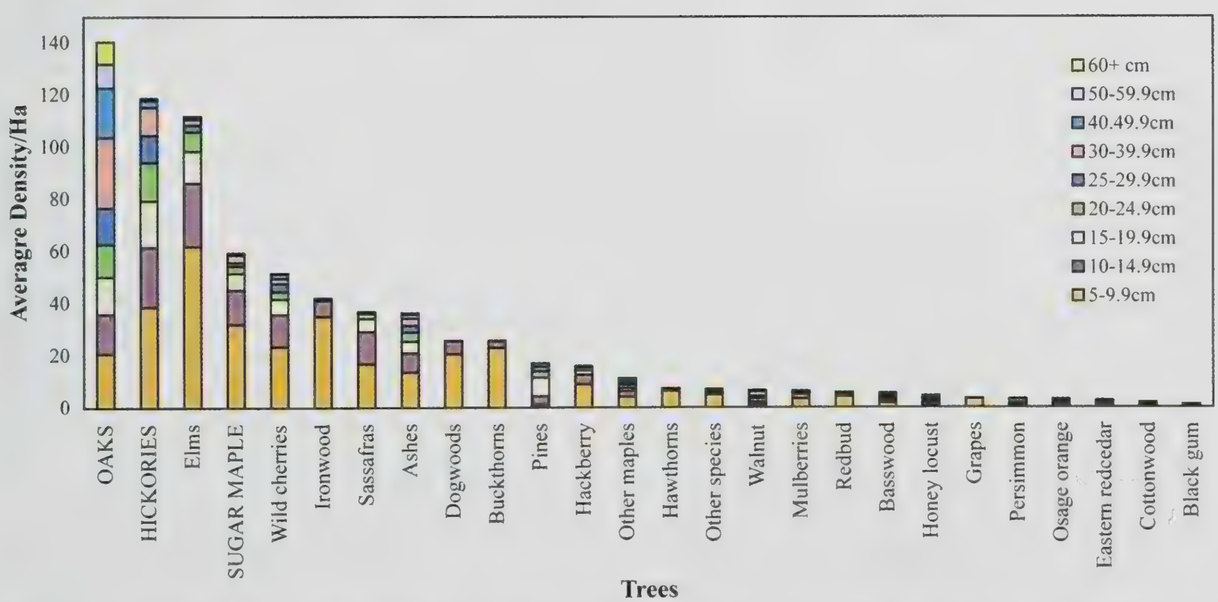

Figure 15.4. Average density of trees among size classes grouped by genus and in some cases species on CTAP random dry to dry-mesic forests (76 sites). Size measured as diameter at breat height (DBH).

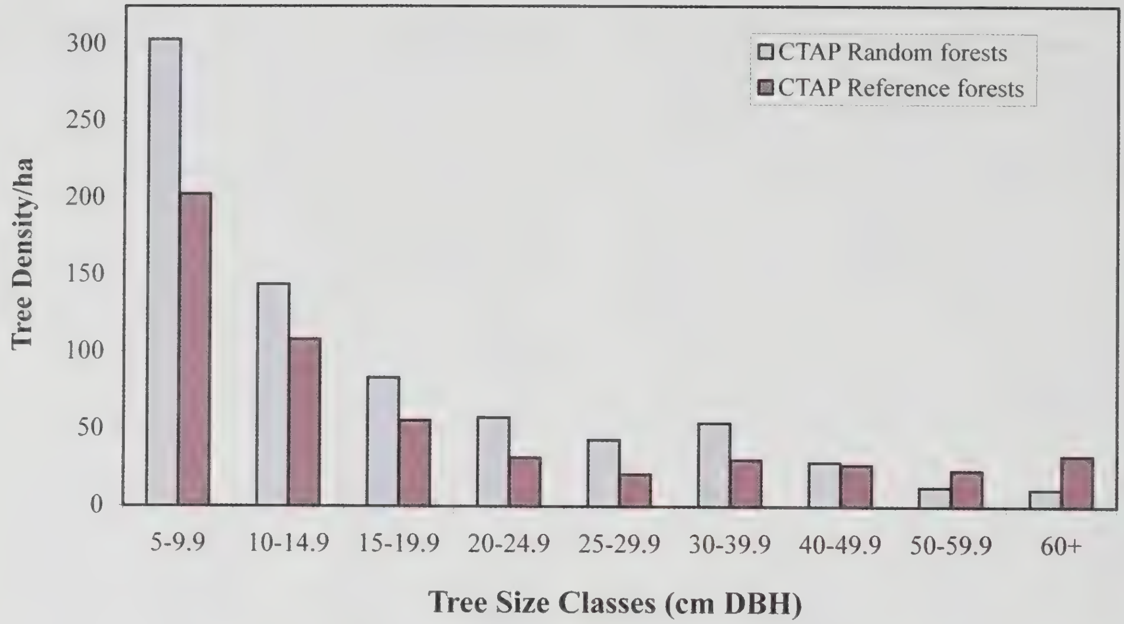

Figure 15.5. Average density per hectare of trees in each size class comparing data from CTAP random and reference forests.

Figure 15.6. Average basal area per hectare of trees in each size class comparing data from CTAP random and reference forests.

The most notable difference in the shrub/sapling layer comparing random and reference forests is the sheer number of stems. The random forests averaged 4,276.5 stems per hectare while the reference forests averaged about 60% of that amount with 2,565.2 stems per hectare, with far less dominance by non-natives (Tables 15.4, 15.5, 15.6).

GROUND LAYER VEGETATION

In the ground layer of random forests, Virginia Creeper was by far both the most frequently encountered and dominant species, occurring on 90.7% of the sites with an average of 6.9% cover and estimated total coverage of 694 meters^2/hectare (Table 15.5). On reference sites, Virginia Creeper was again the most commonly found species, but Canada Wood Nettle (*Laportea canadensis*) was the overall dominant species in the ground layer with 8.2% cover and average coverage of 818 meters^2/hectare (Table 15.4). Percent cover of all ground layer vegetation was about 55% in random forests and 47.5% in reference forests. Random forests also had slightly greater species density averaging 5.3 species per quadrat (1/4-m^2) compared to 4.0 for reference forests.

FOREST CHANGES

General site conditions on the majority of CTAP forests changed very little during the five-year interval between sample cycles, but a few noteworthy changes did occur. Thirty-five of the random forests (27%) experienced localized natural or human disturbances between the visits

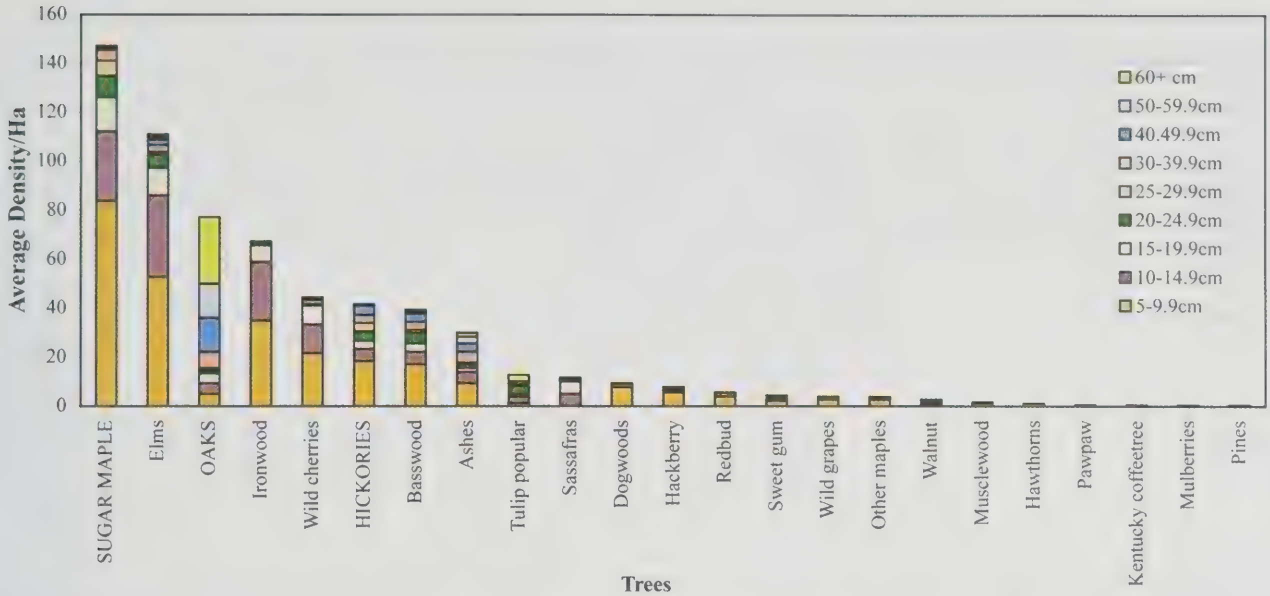

Figure 15.7. Average density of trees among size classes grouped by genus and in some cases species on CTAP dry-mesic reference forests (12 sites). Size measured as diameter at breat height (DBH).

which altered study area conditions to varying degrees:

- 2 sites showed management that included girdling of trees and brush removal
- 3 sites had become lightly grazed by cattle
- 5 sites experienced substantial mortality in canopy trees—undetermined causes
- 6 sites suffered damage from wind storms, two of which showed only minor damage, the remaining four were more severely affected including two sites with strong tornado damage
- 7 sites had been selectively timbered, three rather substantially
- 12 sites showed establishment of trails, mostly from all-terrain-vehicle use.

Natural community responses to disturbances can vary depending on the extent and intensity of the disturbance. Sampled stands with canopy structure damage from storms, logging, or mortality had a flush of more light-dependent species such as Multiflora Rose, blackberries (*Rubus* spp.), and Poison Ivy (*Toxicodendron radicans*) in the understory. Sites that experienced more localized, minimal disturbances such as the introduction of small trails generally showed a decrease in plant diversity in the plots that were directly affected by the activity.

PROBLEM INVASIVE SPECIES

One common concern among landowners and managers across all sites is the encroachment of invasive plants into natural communities. Invasive plants (usually non-native) are species that once established in an area have the potential to increase greatly at the exclusion of many other species. As previously noted, up to 87% of random sites contained at least one potentially invasive species during both visits, whereas 52% of the reference sites contained such problem species (Table 15.3). Some non-native species that pose serious management problems in Illinois forests include Garlic Mustard (*Alliaria petiolata*), Amur Honeysuckle (*Lonicera maackii*), Japanese Honeysuckle (*Lonicera japonica*), Common Buckthorn (*Rhamnus cathartica*), and Multiflora Rose (see Chapter 12). During CTAP's first sampling cycle, the ground layer in 18 of the 129 random sites contained Garlic Mustard, which dominated 5 sites. On the second visit to random sites, Garlic Mustard was recorded in 13 additional sites, and was the most dominant species at 7. Similarly, the presence of Multiflora Rose in the shrub layer increased from 58 to 78 of the random sites, dominating 7.8% and 12.4%, respectively, and Amur Honeysuckle increased from 17 to 36 sites between sample periods, dominating 0% to 6%, respectively (Table 15.6).

CONCLUSIONS

Long-term monitoring programs such as CTAP, with permanent plots in various habitats, provide an unparalleled ability to document both beneficial and detrimental changes in the general conditions of areas as well as the distribution and frequency of numerous species or populations. With just one cycle of return visits to sites, we have already documented the increase of invasive plant species to some areas, as mentioned earlier. Future visits will also provide for the potential detection of new invasive pathogens, such as the emerald ash borer and beech bark disease, which are just now beginning to encroach into some Illinois forests. Early detection of these species and pathogens is essential toward effective management that can help keep them from becoming a serious problem. In those cases where the conditions are beyond management, CTAP can provide a unique documentation of the shifts in forest compositions as some species fall to these pathogens and the forest communities readjust to a new equilibrium. We have also learned that in general, most CTAP forests are in fairly healthy condition. Similar to the USDA Forest Inventory and Analysis data (see Chapter 4, Fig. 4.31), the majority of CTAP random sites are oak-hickory dominated forests of intermediate age that have experienced a variety

Table 15.4. Top 10 species in each vegetation layer from CTAP Reference Forests in descending order of highest Importance Value (IV). See Definitions in Table 15.2. Nomenclature follows Mohlenbrock 1986. * Denotes introduced species.

REFERENCE FOREST SITES

TREES

Common Name	IV (300)	% of Sites dominant	% of Sites present	Average DBH (cm)
Sugar Maple	37.7	17.4	52.2	15.0
White Oak	29.7	26.1	56.5	57.1
Slippery Elm	19.8	0.0	73.9	21.3
Silver Maple	19.2	21.7	26.1	35.0
American Elm	17.5	0.0	56.5	13.6
Hop Hornbeam	12.0	0.0	30.4	10.8
Basswood	11.0	4.3	47.8	14.2
Hackberry	10.4	0.0	56.5	15.8
Green Ash	9.8	0.0	47.8	36.2
White Ash	9.6	0.0	39.1	27.3
% of total IV	**58.9%**			

Summary Tree Data

Avg. Tree Density (stems/ha)	532.8
Avg. Basal Area (m2/ha)	34.6
Total # of tree species	66 (2 introduced)

Data pooled across all 23 sites, 69 total plots (3-0.2 ha plots each site).

Tree IV is sum of relative frequency, density, and basal area; total IV = 300

SHRUBS/SAPLINGS

Common Name	IV (200)	% of Sites dominant	% of Sites present
Spicebush	15.3	8.7	21.7
Poison Ivy	14.3	8.7	39.1
Sugar Maple	13.0	26.1	47.8
Papaw	11.7	4.3	26.1
White Ash	9.7	4.3	30.4
Slippery Elm	9.2	8.7	30.4
Green Ash	9.2	0.0	26.1
Wild Black Cherry	8.9	4.3	21.7
Maple-leaved Arrowwood	7.8	4.3	4.3
Common Choke Cherry	7.2	0.0	21.7
% of total IV	**53%**		

Summary Data

Avg. Shrub/Sapling Density (stems/ha)	2,565.2
Total # of shrub/sapling species	65 (including 7 introduced)

Data pooled across all 23 sites.69 total plots (3-0.01 ha plots each site)

Shrub/Sapling IV is sum of relative frequency and density; total IV = 200

GROUND LAYER

Common Name	IV (200)	% of Sites dominant	% of Sites present
Canada Wood Nettle	17.4	21.7	43.5
Virginia Creeper	14.3	8.7	87.0
Poison Ivy	12.7	13.0	82.6
Clustered Black Snakeroot	7.3	8.7	47.8
Enchanter's Nightshade	7.2	0.0	52.2
Garlic Mustard*	4.9	4.3	21.7
Wild Geranium	4.8	0.0	39.1
Spotted Touch-Me-Not	4.8	4.3	8.7
Canada Clearweed	4.3	0.0	47.8
Feathery False Solomon Seal	3.8	4.3	43.5
% of total IV	**40.8%**		

Summary Ground Layer Data

Avg.ground cover density per site (m2/ha)	4,745.8
Avg # of species per 1/4m2 quadrat per site	4.0
Total # of quadrat species	212 (including 14 introduced)

Data pooled across all 23 sites, 690 total plots (30-0.25 meter2 plots each site).

Shrub/Sapling IV is sum of relative frequency and cover (m2/ha); total IV = 200

Table 15.5. Top 10 species in each vegetation layer from CTAP Random Forests in descending order of highest Importance Value (IV). See Definitions in Table 15.2. * Denotes introduced species. Tree IV is sum of relative frequency, density, and basal area; total IV = 300. Shrub/Sapling IV is sum of relative frequency and density; total IV = 200. Shrub/Sapling IV is sum of relative frequency and cover (m2/ha); total IV = 200.

CTAP RANDOM FOREST SITES

TREES

Common Name	IV (300)	**% of Sites** dominant	**% of Sites** present	**Average** DBH (cm)
American Elm	22.3	6.2	82.2	13.5
White Oak	21.3	14.7	52.7	38.1
Black Oak	15.6	9.3	45.7	32.9
Shagbark Hickory	15.3	4.7	50.4	18.2
Slippery Elm	14.1	4.7	62.0	12.6
Sugar Maple	13.8	11.6	30.2	13.7
Wild Black Cherry	13.6	1.6	62.8	17.0
Hackberry	12.1	3.9	54.3	16.2
Silver Maple	9.5	5.4	15.5	30.6
Bitternut Hickory	8.5	1.6	48.1	17.5
% of total IV	**49%**			

Summary Tree Data

Avg. Tree Density (stems/ha)	737.3	
Avg. Basal Area (m2/ha)	27.3	
Total # of tree species	108	(11 introduced)

SHRUBS/SAPLINGS

Common Name	IV (200)	% of Sites dominant	% of Sites present
Multiflora Rose*	16.8	12.4	53.5
Virginia Creeper	12.1	5.4	73.6
Missouri Gooseberry	10.3	4.7	38.0
Slippery Elm	9.7	4.7	51.2
Amur Honeysuckle*	6.5	4.7	20.2
Hackberry	6.2	1.6	43.4
Poison Ivy	6.2	6.2	43.4
American Elm	6.0	2.3	48.8
Sugar Maple	5.8	8.5	24.8
Wild Black Cherry	5.8	0.0	39.5
% of total IV	42.8%		

Summary Shrub/Sapling Data

Avg. Shrub/Sapling Density (stems/ha)	4,276.5	
Total # of shrub/sapling species	135	(including 19 introduced)

GROUND LAYER

Common Name	IV (200)	% of Sites dominant	% of Sites present
Virginia Creeper	16.8	25.6	90.7
Clustered Black Snakeroot	11.4	14.0	67.4
Canada Wood Nettle	11.4	14.0	34.9
Poison Ivy	6.7	8.5	69.0
Enchanter's Nightshade	5.9	1.6	54.3
Garlic Mustard*	5.4	5.4	24.0
Honewort	4.9	1.6	42.6
Canada Clearweed	3.8	2.3	53.5
Japanese Honeysuckle*	3.6	5.4	17.1
Nodding Fescue	3.5	1.6	43.4
% of total IV	**36.7%**		

Summary Ground Layerv Data

Avg. ground cover density (m2/ha) per site	5,476.0	
Avg # of species per 1/4m2 quadrat per site	5.3	
Total # of quadrat species	479	(including 50 non-native)

Table 15.6. Changes in the presence and dominance of invasive non-native species in CTAP forest monitoring sites.

NON-NATIVE SPECIES	VISIT 1 (129 sites)				VISIT 2 (129 sites)				REFERENCE (23 sites)			
Ground cover layer	**Present**		**Dominant**		**Present**		**Dominant**		**Present**		**Dominant**	
	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total
Garlic Mustard (*Alliaria petiolata*)	18	14.0	5	3.9	31	24.0	7	5.4	5	21.7	1	4.3
Japanese Honeysuckle (*Lonicera japonica*)	24	18.6	5	3.9	22	17.1	7	5.4	2	8.7	-	-
Amur (Bush) Honeysuckle (*Lonicera maackii*)	5	3.9	-		10	7.8	-	-	1	4.3	-	-
Common Buckthorn (*Rhamnus cathartica*)	7	5.4	2	1.6	8	6.2	1	0.8	-	-	-	-
Multiflora Rose (*Rosa multiflora*)	45	34.9	2	1.6	46	35.7	1	0.8	1	4.3	-	-
Shrub layer	**Present**		**Dominant**		**Present**		**Dominant**		**Present**		**Dominant**	
	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total	# sites	% of total
Japanese Honeysuckle (*Lonicera japonica*)	16	12.4	5	3.9	13	10.1	4	3.1	1	4.3	-	-
Amur (Bush) Honeysuckle (*Lonicera maackii*)	17	13.2	-		36	27.9	6	4.7	4	17.4	-	-
Common Buckthorn (*Rhamnus cathartica*)	11	8.5	5	3.9	9	7.0	6	4.7	2	8.7	-	-
Multiflora Rose (*Rosa multiflora*)	58	45.0	10	7.8	78	60.5	16	12.4	3	13.0	-	-

of disturbances, producing sites with a wide diversity of species, many of which tolerate or thrive with some level of disturbance. Conversely, CTAP reference sites are older-growth stands dominated by large oaks subtended by Sugar Maples and elms in the smaller size classes with very little oak regeneration. These sites have experienced little human disturbance, have lower density tree and shrub layers, and harbor species that include both disturbance-tolerant and slightly more conservative (less weedy) species. Similar results were found in a previous comparison using a smaller dataset (9).

Management implications that may be gleaned from these data depend on goals and objectives with forest habitats, which can be as varied as the landowners. Landowners wishing to favor more wildlife may choose to maintain standing dead snags and manage for native shrub layers and species that provide cover and food for various fauna. Maintenance or restoration of an oak-hickory composition may require the introduction of moderate disturbances such as prescribed burning and thinning of shade-tolerant species.

Other CTAP studies have documented information such as the importance of habitat size and quality for bird species dependent on grassland, forest, and wetland habitats, the correlation of stream water quality and the presence of sensitive aquatic macroinvertebrates, as well as new county and state records for some leafhopper species and aquatic stoneflies (6, 14, 15).

This summary of CTAP monitoring provides just the beginning of information that can be gained from long-term monitoring of natural communities in Illinois. While these baseline and second-cycle sample data provide valuable information on current conditions, the major benefits from this unique monitoring program will be realized more fully in future years with the ability to detect changes and trends over longer periods of time.

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CHAPTER 16

Potential Changes in Tree Habitat for Illinois under Climate Change

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OBJECTIVES

One of the many applications of biological field data is their inclusion in predictive models. Such models are now being used to address questions facing society such as how will forest vegetation respond to a warming climate? What tree species are likely to be affected most? Models have been developed to help scientists predict how species might respond under a variety of future climatic scenarios. This chapter introduces some of the ways these predictions are being made and what the future may hold for Illinois trees.

INTRODUCTION

Global climate change increasingly is a factor influencing environmental and public policy. Understanding how these changes will affect vegetation is vital to making predictions about future conditions and in conservation planning.

An increasing number of cases are appearing in the scientific literature documenting changes in species patterns such as the timing of migration, flowering dates, timing of appearance in the spring, or disappearance in the autumn (1). Evidence is mounting that these changes will continue to accelerate through the twenty-first century. Though the habitats for trees change slowly relative to most animals and many herbaceous plants, the fossil record and multiple models show that they too are destined for changes in composition and abundance. Even though large lag times may occur due to long life spans for trees, catastrophic events such as ice storms or fires could hasten the changes to trees.

To address future impacts of climate change on trees, the potential changes in suitable habitat for 134 tree species in the eastern United States have been modeled (2, 3) including model outputs for Illinois. Detailed procedures for this analysis have been presented elsewhere (2, 4, 5) and are summarized here. These models represent *potential change* in suitable habitat by 2100, not what we expect the species range and abundance to be in that year. Other factors (e.g., changes to land cover, biotic and abiotic interactions not considered in the model) likely will have important influences on distribution and abundance of tree species.

METHODS

MODEL AND DATA PREPARATION include the following steps: 1) Calculate importance values (IV) for each tree species, based equally on number of trees and tree basal area (stem area at 4.5 ft. above ground) in more than 100,000 plots from the United States Department of Agriculture (USDA) Forest Service's Forest Inventory and Analysis (FIA) sample sites. 2) Create 20- by 20-km grid of nearly 10,000 cells within the eastern United States (east of 100th meridian). 3) Summarize IV by 20- by 20-km cells. 4) Select species that met the criterion of being present in at least 50 cells (n=134). 5) Prepare 38 predictor variables that characterize individual species' habitat preferences based on current climate, elevation, and soil type. 6) Calculate weighted averages for each predictor variable by cell.

MODEL RUNS are tested with the following procedure: 1) Run Regression Tree Analysis (RTA), a sequence of statistical tests used to estimate importance values for tree species as influenced by the 38 predictor variables. 2) Determine stability of RTA models based on the variation among 30 individual runs of RTA for each species. 3) Create a robust predictive model of current and potential future importance values for each species using a statistical procedure called Random Forests (4). This procedure makes predictions of species' importance values based on the 38 input variables, including seven climate variables derived from past climate data (1960–1990). 4) Project the models onto scenarios of future climate to attain importance values for trees based on expected occurrences of suitable habitat. For this, the seven current climate variables were substituted with projected future climate estimates (2070–2100) according to three different climate models and two projected CO_2 emission levels (high and low). Differences between high and low emissions result from the energy and consumption choices humans make over the next few decades (high [hi] = humans stay on a similar track of increasing CO_2 emissions over the next 50 years, then emissions level off but end the century with roughly triple [970 ppm] the pre-industrial levels for CO_2; low [lo] = with increased conservation of energy we could end the century at about 550 ppm CO_2). The three climate models, known by their acronyms PCM, GFDL, and HadleyCM3, predict mild, moderate, and harsh future climates. To generalize

information from these climate models, their outputs were averaged (Global Circulation Model average [GCM3]) under high and low emissions and reported as GCM3lo and GCM3hi, in addition to the projected mildest (PCMlo) and harshest (HADhi) scenarios.

OUTPUTS. Data generated from the model runs were used to map current and potential future suitable habitat. Maps of predicted current distribution were compared to recently collected FIA data to test the accuracy of the models. Also assessed was the relative importance of variables in predicting suitable habitat using outputs from the statistical procedures. Variable interactions, scale of influence, and relationship of predictor variables to RTA tree diagrams and maps were assessed. Finally, potential changes in suitable habitat under various climate scenarios were examined.

RESULTS AND DISCUSSION

Projected changes in climate across the eastern United States are anticipated to vary regionally and in magnitude based on the emission scenario and climate model. For example, under GCM3lo and GCM3hi emissions, the mean annual temperature is projected to increase by 3.0 and 5.7 C, respectively (Fig. 16.1).

OUTPUT AND SIGNIFICANCE OF THE CLIMATE CHANGE MODELS

It should be emphasized that these procedures merely model the potential suitable habitat changes and not the realized niche space. That is, there is no claim that the species will actually migrate to that space in the time frame of the future climate models. There are many other factors such as disturbance, competition, and land-use changes that are beyond the scope of this modeling framework. Researchers expect that disturbance agents more likely will hasten declines among species to a greater degree than they would accelerate the prominence of new species entering the region; however, if species already are present, they may increase in importance as competing tree species decrease. Trees generally live a long time and migrate slowly so that great lag times need to be considered to determine actual estimated ranges. This has been attempted for several species using a companion model (SHIFT). Scientists found that lag times and the fragmented nature of remaining forests greatly slow migration rates. For example, for five species tested, less than 15% of the newly created suitable habitat under climate change would have even a 2% chance of being colonized within 100 years (6, 7).

Illinois estimates of potential changes in tree species area-weighted importance values (AW IV) are tallied in Table 16.1 for both low emissions (PCMlo and GCM3lo) and high emissions (GCM3hi and HADhi) scenarios. The results from this modeling effort show that many species, including the most abundant ones, will have sizeable changes in suitable habitat in Illinois over the next century. In general, those species expected to increase or decrease under climate change will do so to a greater extent under higher emissions than lower emissions (Table 16.2). For visual examples, please see the Web site (3, http://www.nrs.fs.fed.us/atlas), which shows dozens of maps for each species. Although an exact timeline cannot be attributed to the potential changes outlined, suitable habitat importance will diminish over the next 100 years for many of the currently important species. These species, in descending order for the absolute loss of area-weighted importance values for the average high emission scenario, include Black Cherry (*Prunus serotina*), American Elm (*Ulmus americana*), White Oak (*Quercus alba*), Sugar Maple (*Acer saccharum*), Black Walnut (*Juglans nigra*), Northern Red Oak (*Q. rubra*), Shagbark Hickory (*Carya ovata*), White Ash (*Fraxinus americana*), and Black Oak (*Q. velutina*). Maps illustrating the potential change in geographic distribution of importance for White Oak, the state tree of Illinois, suggest that under either the high emission (e.g., GCM3hi) or low emission (GCM3lo) scenarios, suitable habitat could decline substantially in the state (Fig. 16.2). Several minor species also are greatly reduced including Paper Birch (*Betula papyrifera*), Eastern White Pine (*Pinus strobus*), Red Pine (*Pinus resinosa*; primarily in Illinois as a planted species), and Bigtooth Aspen (*Populus grandidentata*), suggesting a retreat of the northern forest types (8).

The extent of these changes depends largely on the emission scenario selected by humans over the next century. Changes would be much less dramatic, often less than half, if humans follow a low-emissions pathway. The species listed as potential losers currently provide most of the region's commercial and tourism value. Consequently, the potential economic impacts of such changes are likely to be substantial. Unfortunately, a recent report shows that current global trends of atmospheric carbon already are above that of the high emissions scenario (9). If that continues, for impacts shown here and elsewhere (e.g., 10), we are more likely to go even beyond the 'Hi' CO_2 emissions scenario.

Table 16.1. Potential species changes in importance value*area for habitat suitability for 112 species that currently reside in Illinois. Ratios below 1.0 are habitat loser species, while ratios >1.0 are habitat gainers.

	Ratio of future habitat to present habitat (area-weighted importance value)						
Scenario	< 0.5	0.5 - 0.9	0.9 - 1.1	1.1 - 2	> 2	decrease	increase
PCMlo	30	18	25	26	13	48	39
GCM3lo	29	17	19	35	12	46	47
GCM3hi	29	8	20	26	29	37	55
HADhi	25	7	13	41	26	32	67
Average	28.3	12.5	19.3	32.0	20.0	40.8	52.0

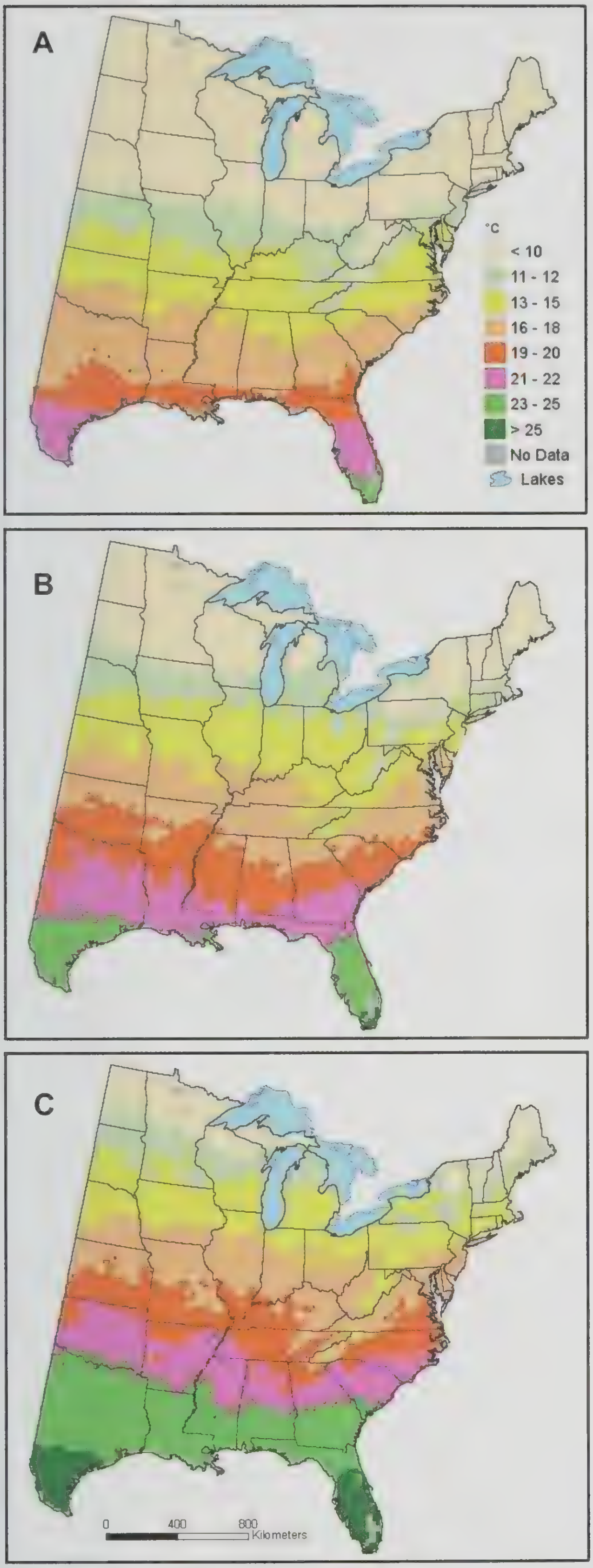

Figure 16.1. Mean annual temperatures (A) for current period (1960–1990), and potential future period (2070–2099) under (B) lower emissions average of three models, or (C) higher emissions (average of three models) scenarios.

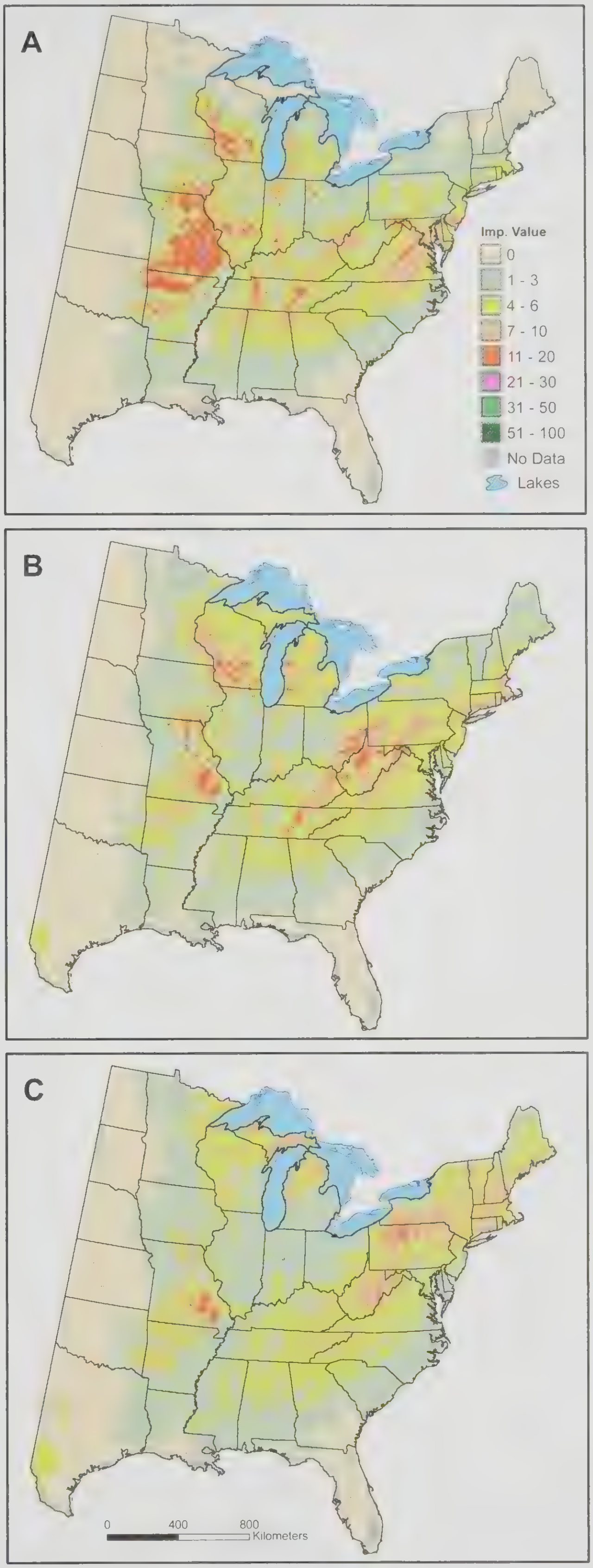

Figure 16.2. Potential suitable habitat for White Oak (*Quercus alba*) at (A) the current time, and potentially at year 2100 under (B) lower emissions or (C) higher emissions.

Table 16.2. Illinois tree species, sorted by decreasing modeled area-weighted importance values (AWIV), and percent potential changes according to four future climate scenarios. Species in red are species with projected major declines in suitable haibitat; species in blue are projected to have increasing suitable habitat. At bottom are five rare species that are in Illinois but not modeled as such; their actual (in parentheses) and estimated future AWIV are presented.

Common Name	Scientific Name	AWIV	PCMLO	GCM3LO	GCM3HI	HADHI
American Elm	*Ulmus americana*	3115	45.2	-9.8	-45.5	-59.9
White Oak	*Quercus alba*	2288	-14.2	-39.6	-57.7	-61.5
Black Cherry	*Prunus serotina*	1876	-38.8	-65.0	-77.6	-78.3
Silver Maple	*Acer saccharinum*	1858	49.1	35.0	45.1	19.1
Hackberry	*Celtis occidentalis*	1704	53.1	17.7	-18.3	-33.5
Black Oak	*Quercus velutina*	1452	1.6	-10.6	-33.3	-47.5
Shagbark Hickory	*Carya ovata*	1356	31.0	-20.2	-43.1	-55.0
Sugar Maple	*Acer saccharum*	1313	-20.0	-48.4	-71.7	- 85.7
Boxelder	*Acer negundo*	1290	18.8	47.3	87.4	65.3
Black Walnut	*Juglans nigra*	1267	63.5	-1.2	-50.4	-78.6
White Ash	*Fraxinus americana*	1182	-5.6	-25.8	-42.5	-53.0
Osage-orange	*Maclura pomifera*	1113	35.9	27.0	17.7	3.3
Green Ash	*Fraxinus pennsylvanica*	1039	65.6	54.5	64.6	72.8
Northern Red Oak	*Quercus rubra*	1015	11.8	-31.6	-61.2	-73.5
Honeylocust	*Gleditsia triacanthos*	967	87.5	54.2	31.7	18.8
Slippery Elm	*Ulmus rubra*	938	37.1	-4.3	-29.5	-47.3
Bur Oak	*Quercus macrocarpa*	790	27.7	19.1	50.9	38.1
Red Mulberry	*Morus rubra*	695	131.5	126.5	111.1	87.6
Shingle Oak	*Quercus imbricaria*	681	16.3	-2.2	-14.5	-20.0
Eastern Hophornbeam	*Ostrya virginiana*	679	16.2	-28.6	-46.7	-43.4
Red Maple	*Acer rubrum*	674	-8.8	-22.0	-16.6	-9.3
Sassafras	*Sassafras albidum*	667	2.2	-18.6	-32.4	-43.5
Eastern Cottonwood	*Populus deltoides*	664	46.4	34.3	20.2	9.5
Pignut Hickory	*Carya glabra*	598	-15.4	-28.6	-28.3	-17.7
Bitternut Hickory	*Carya cordiformis*	582	92.6	16.0	8.4	-5.5
Black Willow	*Salix nigra*	581	51.5	40.8	93.8	28.9
Sycamore	*Platanus occidentalis*	497	34.2	25.8	15.5	14.9
American Basswood	*Tilia americana*	475	-13.7	-21.3	-1.9	-31.4
Pin Oak	*Quercus palustris*	447	87.5	25.5	10.5	5.6
Mockernut Hickory	*Carya tomentosa*	431	29.0	24.6	29.0	39.9
Eastern Redcedar	*Juniperus virginiana*	422	110.2	120.1	166.4	169.2
Black Locust	*Robinia pseudoacacia*	395	29.6	119.2	7.3	-35.9
Flowering Dogwood	*Cornus florida*	317	42.3	17.7	30.9	38.8
Sweetgum	*Liquidambar styraciflua*	253	73.1	85.4	172.3	272.3
Eastern Redbud	*Cercis canadensis*	237	97.9	52.3	-6.3	-48.9
Common Persimmon	*Diospyros virginiana*	227	149.8	141.4	234.4	258.6
Eastern White Pine	*Pinus strobus*	173	-81.5	-92.5	-97.1	-98.3
River Birch	*Betula nigra*	139	109.4	77.0	260.4	174.1
Yellow-poplar	*Liriodendron tuliperfia*	134	114.9	-43.3	-8.2	2.2
Chinkapin Oak	*Quercus muehlenbergii*	131	228.2	175.6	102.3	42.0
Red Pine (cultivated)	*Pinus resinosa*	118	-61.9	-61.9	-58.5	-55.1
Winged Elm	*Ulmus alata*	116	737.9	1404.3	2500.0	2880.2
Swamp White Oak	*Quercus bicolor*	115	152.2	67.8	-27.8	-77.4
Black Ash	*Fraxinus nigra*	90	-73.3	-42.2	114.4	11.1
Quaking Aspen	*Populus tremuloides*	85	-91.8	-88.2	94.1	-64.7
American Beech	*Fagus grandifolia*	78	-53.8	-73.1	-75.6	-66.7
Shortleaf Pine	*Pinus echinata*	78	67.9	174.4	433.3	707.7
Blackgum	*Nyssa sylvatica*	74	62.2	33.8	127.0	232.4
Northern Pin Oak	*Quercus ellipsoidalis*	64	-29.7	-7.8	207.8	79.7
Blackjack Oak	*Quercus marilandica*	63	482.5	704.8	939.7	933.3
Jack Pine	*Pinus banksiana*	49	-24.5	32.7	326.5	151.0
Pawpaw	*Asimina triloba*	48	197.9	14.6	-14.6	-62.5
Sugarberry	*Celtis laevigata*	48	972.9	1775.0	2447.9	2454.2

Table 16.2 continued on next page

Common Name	Scientific Name	AWIV	PCMLO	GCM3LO	GCM3HI	HADHI
Southern Red Oak	*Quercus falcata* var. *falcata*	39	376.9	684.6	1297.4	1774.4
Shellbark Hickory	*Carya laciniosa*	37	264.9	140.5	108.1	54.1
Scarlet Oak	*Quercus coccinea*	35	-40.0	-77.1	-82.9	-77.1
American Hornbeam	*Carpinus caroliniana*	35	-8.6	-8.6	31.4	91.4
Ohio Buckeye	*Aesculus glabra*	34	8.8	-14.7	-67.6	-70.6
Bigtooth Aspen	*Populus grandidentata*	31	-96.8	-100.0	-100.0	100.0
Black Hickory	*Carya texana*	31	819.4	1100.0	1509.7	1490.3
Wild Plum	*Prunus americana*	30	33.3	373.3	1080.0	793.3
Willow Oak	*Quercus phellos*	22	209.1	359.1	572.7	727.3
Loblolly Pine	*Pinus taeda*	22	463.6	909.1	3036.4	5627.3
Chestnut Oak	*Quercus prinus*	19	-63.2	-84.2	-78.9	-68.4
Post Oak	*Quercus stellata*	19	-63.2	-84.2	-78.9	-68.4
Cherrybark Oak	*Quercus falcata* var. *pagodaefolia*	19	147.4	326.3	563.2	752.6
Paper Birch	*Betula papyrifera*	15	-80.0	-80.0	-73.3	-93.3
Pecan	*Carya illinoensis*	13	2676.9	2569.2	3815.4	3892.3
Butternut	*Juglans cinerea*	11	-90.9	-100.0	-100.0	-100.0
Overcup Oak	*Quercus lyrata*	10	90.0	210.0	420.0	700.0
Northern Catalpa	*Catalpa speciosa*	8	-50.0	-12.5	25.0	12.5
Kentucky Coffeetree	*Gymnocladus dioicus*	8	875.0	1012.5	950.0	750.0
Chokecherry	*Prunus virginiana*	7	-42.9	-85.7	-85.7	-100.0
Virginia Pine	*Pinus virginiana*	7	-42.9	-71.4	-57.1	-57.1
Black Maple	*Acer nigrum*	5	-100.0	-100.0	-100.0	-100.0
Rock Elm	*Ulmus thomasii*	5	-20.0	-100.0	-80.0	-80.0
Northern White-cedar	*Thuja occidentalis*	4	-100.0	-100.0	-100.0	-100.0
Eastern Hemlock	*Tsuga canadensis*	4	-75.0	-75.0	-75.0	-75.0
White Spruce	*Picea glauca*	4	-75.0	-75.0	-75.0	-75.0
Balsam Poplar	*Populus balsamifera*	4	-25.0	- 50.0	-75.0	-75.0
Yellow Birch	*Betula alleghaniensis*	3	-100.0	-100.0	-100.0	-100.0
Water Hickory	*Carya aquatica*	3	-66.7	-66.7	-33.3	0.0
Sourwood	*Oxydendrum arboreum*	3	-66.7	-66.7	-66.7	0.0
Bald Cypress	*Taxodium distichum*	2	150.0	100.0	150.0	250.0
Water Tupelo	*Nyssa aquatica*	2	400.0	250.0	200.0	350.0
Tamarack	*Larix laricina*	1	-100.0	-100.0	-100.0	-100.0
Blue Ash	*Fraxinus quadrangulata*	1	-100.0	-100.0	-100.0	-100.0
Pin Cherry	*Prunus pensylvanica*	1	-100.0	-100.0	-100.0	-100.0
Yellow Buckeye	*Aesculus octandra*	1	-100.0	-100.0	-100.0	-100.0
Swamp Chestnut Oak	*Quercus michauxii*	1	100.0	100.0	100.0	200.0
Swamp Tupelo	*Nyssa biflora*	1	-100.0	-100.0	-100.0	-100.0
Cittamwood/Gum Bumelia	*Bumelia lanuginosa*	0(1)	0	0	0	0
American Chestnut	*Castanea dentata*	0(2)	0	0	0	0
Peachleaf Willow	*Salix amygdaloides*	0(4)	1	1	1	1
Cucumbertree	*Magnolia acuminata*	0(5)	2	2	2	2
Shumard Oak	*Quercus shumardii*	0(8)	8	75	87	54

Coupled with the reduced habitat for these primary species are the pests and diseases that are threatening several of the same species, such as Emerald Ash Borer on ash (11, 12), Dutch Elm Disease on elms (13), Spruce Budworm, Pine Bark Beetle, White Pine Blister Rust, Beech Bark Disease, and maple decline (cited in 14). As of 2005, Dutch Elm Disease was reported to cause moderate to heavy mortality in 45 Illinois counties (15). Thus, the compositional changes will be accelerated. Warming also tends to accelerate the rate of insect development and facilitate range expansions of pests and diseases such as those listed above. When climate change produces a mismatch between mature trees and the habitat upon which they live, there can be increased vulnerability to pests and pathogens (14). Invasive plants also are likely to spread under climate change as niches open, because the invaders are adapted to wider conditions and rapid colonization and growth could occur after disturbance or elevated CO_2 (16, 17). Of course, other human-derived disturbances associated with changes in land use and land cover have had, and will continue to have, profound impacts on the species composition (18).

Beyond the disturbances associated with insects and disease, a changing climate will increase the potential for other disturbances. Climatic effects such as increases in wind and ice damage, hurricane intensity, heavy precipitation events, drought in the later parts of the growing season, flooding during the growing season, and warmer winter and summer temperatures (19) can increase stress on species, leading to further changes. An analysis of 806 northern temperate trees and shrubs showed that few species can tolerate more than one of the following stresses: shade, drought, or waterlogging (20). Climate change will modify the proportions of these stresses (e.g., increases in both drought and waterlogging potential leading to changes in species composition). Additonally, though not so much a factor for Illinois, wildfire is liable to increase under climate change, at least in some portions of the country (21), and this could have a substantial effect on hastening species changes that are undergoing shifts in their habitat suitability.

Concurrently, some species will likely increase substantially in habitat importance in Illinois. These include several oaks: Southern Red (*Quercus falcata* var. *falcata*), Blackjack (*Q. marilandica*), and Bur (*Q. macrocarpa*); two hickories: Black (*Carya texana*) and Pecan (*C. illinoensis*); two pines: Loblolly (*Pinus taeda*; not currently native in Illinois) and Shortleaf (*Pinus echinata*); two maples: Silver (*Acer saccharinum*) and Box Elder (*A. negundo*); and Sugarberry (*Celtis laevigata*), Sweetgum (*Liquidambar syraciflua*), and Winged Elm (*Ulmus alata*). Shortleaf Pine, a southern species currently limited to far southern Illinois, is modeled to have a large net increases in habitat (Table 16.2), potentially resulting in a dramatic shift northward (Fig. 16.3). Increased habitat for oaks and hickories could indicate an increased commercial and wildlife resource, but oaks are currently undergoing a regeneration crisis in the absence of fire or other agents that can partially open the canopy (22, 23, 24). It is possible that some of the disturbances mentioned may open the canopy sufficiently to enhance the probability of oak regeneration. Additional research on this topic is

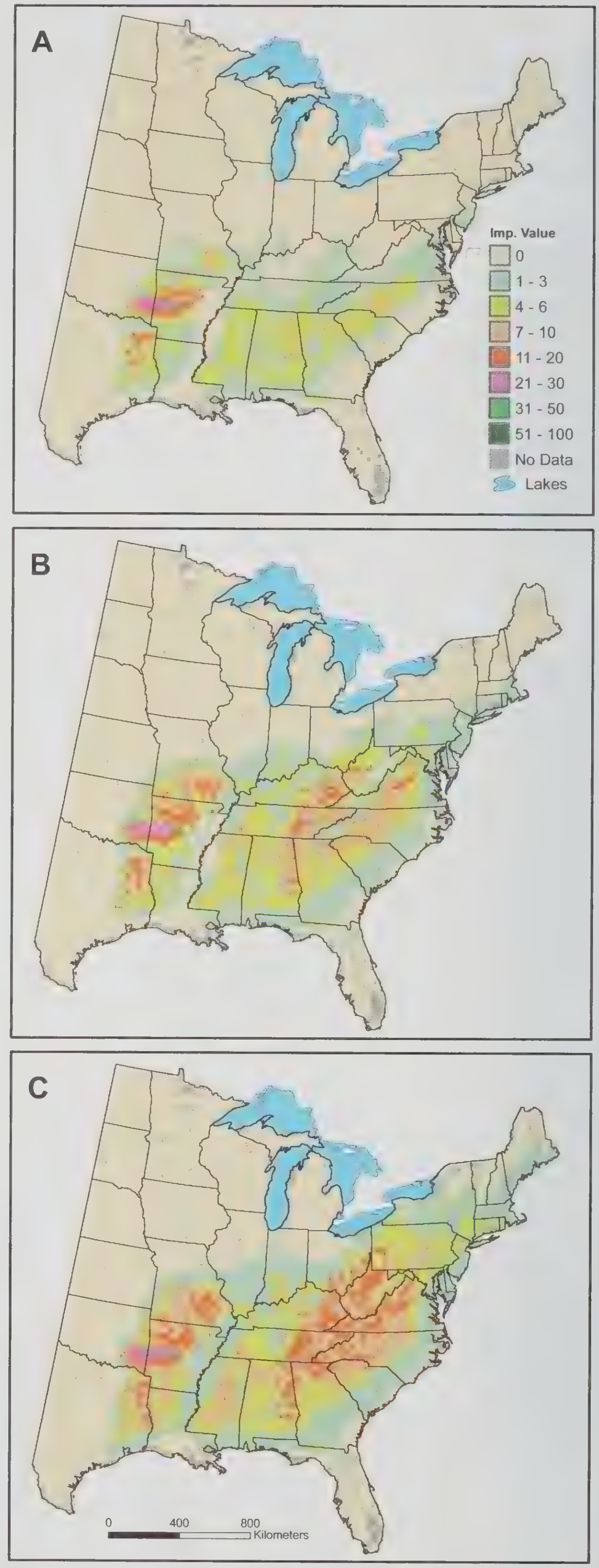

Figure 16.3. Potential suitable habitat for Shortleaf Pine (*Pinus echinata*) at the (A) current time, and potentially at year 2100 under (B) lower emissions or (C) higher emissions.

needed. Another series of species may enter Illinois from the south, including Water Oak (*Quercus nigra*), and Cedar Elm (*Ulmus crassifolia*), or greatly expand from the southern tip of Illinois such as Willow Oak (*Quercus phellos*) and Water Locust (*Gleditsia aquatica*).

The overall changes in potential suitable habitat reflected in these models reveal that, in general, there is a broad-scaled loss in habitat for many common upland species (but not complete loss—their habitats will remain but with lower suitability). There also would be a loss in habitat for species characterized as "northern" with the southern edge of their ranges moving north (and mostly out of Illinois). Finally, there would be a series of southern, and especially bottomland, species that have the northern edge of their habitat ranges moving northward to cover more area within Illinois.

These models show that species projected to have increasing suitable habitat outnumber those with decreasing habitat (Tables 16.1 and 16.2). Moreover, as the scenarios vary from PCMlo ("mild") scenario, to the average low and high emission scenarios, and to the HADhi ("harsh") scenario, the ratio of gainers to losers increases (Table 16.1). This trend can be partially explained by the nature of the biogeography associated with the ranges of tree species. In relation to the boundaries of Illinois, there is much territory and a great diversity of species towards the south but less territory and species diversity towards the north. Also, Canada is outside the range of FIA data, so exclusively Canadian species are not included in the models. However, the pressures (backed by paleo and ever increasing present-day data) are for the species to migrate northward; so it is logical that many southern species, especially ones driven largely by climate (particularly temperature), would gain suitable habitat within the boundaries of Illinois.

CONCLUSIONS

Climate change will provide a driving force over the next decades to alter the forest composition in Illinois. These changes can be expected to be gradual given lengthy life spans for most trees. Just because the climate is more suitable for a different species does not mean that already established trees will not survive well beyond the time their habitat is no longer suitable. Thus, it is not possible to put a time frame on the compositional changes discussed here. The larger, more noticeable, changes are likely to occur from direct human impacts like land-use change and land management, or from large disturbance events such as ice storms, severe droughts, and wildfires. However, large disturbance events also could accelerate forest compositional changes as discussed here.

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CHAPTER 17

Stemming Wetland Losses—From the Legislature to the Field

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OBJECTIVES

The development and legal debates concerning federal legislation and regulations designed to protect wetland functions are introduced. These legal issues are followed by an account of the developing science and practice of wetland restoration and mitigation.

INTRODUCTION

Historically, the prevailing attitude regarding wetlands was that they were wastelands with virtually no value or redeeming qualities, nothing more than swamps filled with poisonous snakes and swarms of disease-carrying mosquitoes. Considered obstacles to development and travel, they were drained or filled and claimed for other uses. At the time of European settlement, it is estimated that 221 million acres of wetland existed in what would become the lower 48 states. Today, 51% of that acreage has been altered and is no longer wetland. Six of the lower 48 states, including Illinois, have lost 85% or more of their wetland areas (1). In Illinois, the majority of these former wetlands was converted to agriculture, now the dominant land use in much of the state, leading to loss of 88% of wetland area (Plocher unpub. data; see Chapter 5). Only in recent decades have the functions and values of wetlands become better understood. This general change in attitude has led to the implementation of wetland protection and preservation legislation at both the federal and state levels. Subsequently, the science and application of wetland restoration and wetland mitigation have developed, with the goal of helping to replace the vast acreages of lost or degraded wetlands across the United States.

WETLAND LEGISLATION AND RECENT SUPREME COURT DECISIONS

Meaningful protection of wetlands at the federal level began in the 1970s. This was due to 1) increased public concern for the environment, 2) evidence that wetlands were being lost a rate that would soon result in their disappearance in a number of states, and 3) recent realization that wetlands have both economic and functional value for society (2). In 1977 President Jimmy Carter issued Executive Order 11990, which established the protection of wetlands as a policy of the federal government. And in his 1990 budget address, President George H. Bush endorsed the National Wetlands Policy Forum recommendation of "No Net Loss" of wetlands as a national goal. The Clinton and George W. Bush administrations have both echoed these endorsements in public statements. Even so, after 30 years, there is still no specific national wetland law; instead, wetland protection results from the application of a number of laws intended for other purposes (3).

The primary source of wetland protection and regulation in the United States is Section 404 of the Federal Water Pollution Control Act amendments of 1972 and the subsequent 1977 amendments, known as the Clean Water Act. Interestingly, wetlands are not directly mentioned in either the FWPC Act or its 1972 amendments (3). The objective of the act is to maintain and restore the chemical, physical and biological integrity of the "Waters of the United States," and Section 404 authorizes the Army Corps of Engineers (ACOE) to regulate the discharge of dredged or fill material into these waters (4). At first, this legislation was interpreted narrowly by the ACOE to apply only to navigable waters. However, in a 1975 court case challenging further dumping by the U.S. Navy of polluted dredge spoil at the New London Dumping Site in Long Island Sound (Natural Resources Defense Council v. Calloway), the court invoked the Commerce Clause of the U.S. Constitution to expand the ACOE's regulatory authority over water bodies to include tributaries and wetlands (3, 5). For Clean Water Act purposes, Waters of the U. S. is now defined as waters "navigable in law;" interstate waters; waters currently used, used in the past or that may be susceptible to use in interstate or foreign commerce; tributaries of these waters; the territorial seas; and wetlands adjacent to (defined as neighboring) all of the above (6). In 1986, the ACOE adopted the Migratory Bird Rule, an administrative interpretation stating that the presence of migratory bird aquatic habitat was sufficient to make such habitat jurisdictional under the Clean Water Act, based on the Commerce Clause of the U. S. Constitution (7).

There are numerous potentially serious problems with the manner in which legislation for protection and regulation of wetlands has developed at the federal level. The over arching problem is that there is no specific national wetland law in spite of most presidential administrations

over the last 30 years endorsing wetland protection as an important federal policy. Another serious problem is that several means of wetland destruction such as draining, permanently flooding, or introduction of toxic compounds (e.g., herbicides) are not covered under Section 404 of the Clean Water Act (8). In fact, the use of Section 404 for wetland protection has been controversial and has been the subject of a number of court actions, primarily from home builders, industry and agriculture. The controversy is due to wetlands not being mentioned in the original Federal Water Pollution Control Act, a disagreement over what constitutes Waters of the U.S. and navigable waters, and the meanings of the terms tributary and adjacent being unclear (3, 7). Several U.S. Supreme Court cases illustrate the uncertainties surrounding existing wetland policy.

From the 1970s until 2001, lower courts and the Supreme Court broadly upheld ACOE Clean Water Act regulations and jurisdiction over wetlands and other waters. In the 1985 Supreme Court case United States v. Riverside Bayview Homes, the court unanimously endorsed ACOE jurisdiction over an 80-acre marsh in Michigan that was adjacent to (neighboring) but not abutting a navigable creek. Occasional surface runoff into navigable waters was found sufficient to constitute a meaningful connection (7). However, in Illinois in 1997, the Solid Waste Agency of Northern Cook County (SWANCC) sought to obtain a Section 404 permit to establish a sanitary landfill on an area of abandoned gravel pits that were, for the most part, nonwetland ponds, although a small amount of disturbed wetland was included (USFWS pers. comm.). Because the site included a heron rookery and served as habitat for several waterfowl species, the ACOE denied the permit, basing its jurisdiction on the Migratory Bird Rule. SWANCC filed suit and, on appeal, the U.S. Supreme Court in 2001 ruled in a narrow (5-4) decision that Congress did not intend Section 404 to regulate isolated waters based solely on use by migratory birds. The court did recognize that Congress intended the phrase "navigable waters" to include at least some waters that would not be deemed navigable in the traditional sense and that Congress' concern for the protection of water quality indicated its intent to regulate wetlands "inseparably bound up with" waters of the U.S. Although from 2001, isolated wetlands (jurisdiction solely based on migratory bird use) no longer received federal protection, lower courts narrowly interpreted SWANCC. Courts repeatedly held that wetlands were subject to Clean Water Act jurisdiction if they were adjacent to (neighboring) navigable waters or their tributaries or had clear surface hydrologic connection to Waters of the U.S. (7).

In 2006, the Supreme Court consolidated for review two lower court cases from Michigan, Rapanos v. United States and Carabell v. ACOE. The court was asked to decide whether Section 404 of the Clean Water Act extends to wetlands not adjacent to navigable waters. The Rapanos case involved three parcels with a total of 141 acres of wetland. All wetlands had clear surface water connections to tributaries or drains with perennial connection to navigable waters. The Carabell case involved a 16-acre forested wetland separated from a 100-year-old ditch by a man-made berm. The ditch connects to a creek that flows into navigable waters. The ACOE had determined that the Clean Water Act applied in both cases because the wetlands were connected through tributaries or drains to navigable waters (Rapanos) or were adjacent to ditches connected to navigable waters (Carabell). The Supreme Court vacated judgments against Rapanos and Carabell and remanded the cases to lower courts for further review. The court was even more sharply divided than in SWANCC (4-1-4), issuing five separate opinions, none of which commanded a majority. The only thing a majority of the court could agree on was that the lower courts did not employ a rigorous enough test to determine whether the wetlands were subject to Clean Water Act jurisdiction. Four justices narrowly interpreted Clean Water Act jurisdiction in a plurality opinion that overturned the lower court cases. Justice Kennedy wrote a separate opinion joining the plurality but not agreeing with the plurality's reasoning. The four remaining Justices joined in a dissent supporting the ACOE jurisdictional determinations and a broad interpretation of the Clean Water Act. With no majority opinion, Kennedy's opinion, which provides the "narrowest grounds" which would be supported by a majority, holds. In Kennedy's opinion, the lower courts had not sufficiently demonstrated a "significant nexus" between the wetlands and navigable waters (although, in all probability, a "significant nexus" does exist). In Kennedy's opinion, he states "wetlands possess the requisite nexus if either alone or in combination with similarly situated lands in the region, they significantly affect the chemical, physical, and biological integrity of other waters more readily understood as navigable" (9). Since there is no common denominator between Justice Kennedy's concurrence and the plurality opinion, overlap between Kennedy and the dissent is in the majority. This approach (adopted by the ACOE and the Environmental Protection Agency [EPA]) holds that wetlands are jurisdictional if they meet Justice Kennedy's "significant nexus" test or if they are adjacent to navigable water or there is a surface hydrological connection to a seasonal (relatively permanent) tributary. Significant nexus must either be determined on a case-by-case basis or determined for certain categories of tributaries deemed to have important functions for navigable waters (10). At any rate, establishing significant nexus is likely to be expensive and time consuming for the regulatory agencies. The Rapanos decision will greatly restrict the federal government's ability to engage in civil or criminal enforcement actions involving wetlands adjacent to non-navigable waters (11).

The purpose of the Clean Water Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Wetlands are inarguably vital to improving water quality (chemical), storing floodwaters (physical), and providing crucial habitat for native plants and animals (biological) in systems involving waters of the U.S. Further, in order to maintain the integrity of waters of the U.S., courts have repeatedly ruled that tributaries must be regulated in order to prevent polluters from simply moving upstream and using tributaries as open sewers into navigable waters (10, 12). Isolated wetlands

provide most of the functions provided by wetlands in general. They are more important for flood control, water quality improvement, and crucial habitat for certain biota (amphibians) (13). Yet in spite of the fact that migratory waterfowl are commercially important and can only be protected through national action, the SWANCC decision removed federal protection for isolated wetlands (jurisdiction based solely on migratory bird use). It is estimated that, nationwide, 40% to 60% of wetlands and 20% to 25% of wetland acreage lost protection due to SWANCC (7). In Illinois, approximately 60% of wetlands (and 12% of wetland acreage) are isolated (13). A number of states have legislation protecting isolated and other wetlands. Fifteen states already had comprehensive wetland legislation in place. Since 2001, five additional states (Ohio, Wisconsin, Indiana, North Carolina, and South Carolina) have adopted legislation to fill the gaps created by SWANCC (7). In Illinois, a comprehensive wetland bill was introduced, but not passed. However, the Illinois Interagency Wetland Policy Act of 1989 does regulate all wetlands on state land or if state agencies or state funding might result in wetland impacts (14).

The extent of the negative effect of the Rapanos decision is still unclear; both the ACOE and the EPA are struggling to provide guidance. However, the effect is certain to be considerable. Following SWANCC, all wetlands with clear surface connection (and some with demonstrated groundwater connection) to navigable waters were under federal jurisdiction. In light of Rapanos, at least some of those wetlands will lose federal protection because the surface connection has not been demonstrated to be hydrologically or ecologically "significant." In addition, the ACOE and EPA lack the staff and budget to make "significant nexus" determinations for thousands of cases per year (10). The Rapanos decision reflects the Court's profound lack of understanding of wetland function in relation to the integrity of waters of the U.S. First, the court considers volume of flow or relative permanence of the tributary to be important because dredged and fill material does not wash downstream as readily as conventional pollutants (12). The fact that dredged and fill activities place wetlands under ACOE jurisdiction does not imply that the dredged and fill materials are the subject of concern. The concern is that the dredged and fill deposition brings an end to the wetland (or other waters), along with functions vital to the integrity of waters of the U.S. Second, it is generally understood that wetlands, in many cases when considered individually and in all cases when considered cumulatively, "significantly affect the chemical, physical, and biological integrity of navigable waters." To suggest that regulatory agencies must, on a case-by-case basis, prove in court that each wetland threatened with impact has a "significant nexus" with waters of the U.S. shows both ignorance of wetland function and of ongoing threats to the health of the nation's waters. As stated in Justice Breyer's separate dissent to Rapanos, "As a result of this decision, courts will have to make ad hoc determinations that run the risk of transforming scientific questions into matters of law" (11).

WETLAND RESTORATION—STEMMING THE LOSS Restoration attempts to aid in the recovery of impaired ecosystems and to help return them to an intact, healthy, and functioning condition (15; see Chapter 13). More specifically, the newly emerging field of wetland restoration aims to re-establish wetland habitats that have been destroyed and to rehabilitate remaining degraded wetlands (16). Wetland restoration is confined to areas where wetlands previously existed or where they still exist in a significantly degraded state. While broadly linked to restoration, wetland creation specifically aims to create wetland habitat in areas where it was never present in the past. In the early stages of these developing fields, "wetlands" were often created in convenient locations, often with little or no thought as to the position of the site within the landscape. Commonly, these created sites were nothing more than excavated depressions located along roadways. These "ponds" were often excavated too deeply and allowed for very little water-level fluctuation, such that vegetation mostly was limited to a narrow ring around the periphery of the site. Many of these created sites never met the jurisdictional definition of a wetland (see Chapter 5) and most contributed only very limited wetland function. In recent decades, much progress has been made in the field of wetland restoration, a practice that has become much more widespread than wetland creation because it is more feasible and the likelihood of success is greater when restoring wetlands on sites where they previously existed (17). Restoration attempts to re-establish wetlands in the landscape position they previously occupied, with the hope of maximizing their functions and values.

Wetland restoration is now widespread across the United States and includes large-scale projects and programs administered by federal and state agencies, as well as many private entities. Within Illinois, numerous wetland restoration projects are scattered throughout the state, although many of the larger ones are concentrated along rivers and involve the restoration of large amounts of floodplain agricultural ground. An early wetlands restoration effort, the Des Plaines River Wetlands Demonstration Project, created in 1985 by Wetlands Research, Inc., was designed as a wetlands research site. Studies at the Des Plaines River site have made significant contributions to our knowledge of wetland restoration. One of the largest private wetland restoration projects in the U.S. has been initiated on the Illinois River floodplain at The Nature Conservancy's 7100-acre Emiquon preserve. Major wetland restoration projects are also underway along the Cache River in southern Illinois. The Cache River Joint Venture Program, a partnership among the Illinois Department of Natural Resources, U.S. Fish and Wildlife Service, The Nature Conservancy, and Ducks Unlimited, has targeted a 60,000-acre corridor along the Cache for wetlands protection and restoration.

As this field of wetland restoration has evolved, information has become available on how to properly go about restoring wetland habitat. A wetland restoration and creation guide was developed for Illinois (18) to provide the public with necessary background information and

resources, as well as step-by-step procedures for wetland restoration. Successful wetland restoration must first begin with proper planning. Setting goals and objectives is an important initial step in wetland restoration process. A wetland's function is more important than its ultimate appearance when planning and designing a restoration (3). Wetland functions to be restored might include flood water or storm water storage, sediment removal from surface water runoff, waterfowl breeding habitat, or provisions for biodiversity. In conjunction with planning for wetland function is deciding the type of wetland to be restored. For instance, in Illinois these might include forested wetland, wet prairie, or marsh. It is generally considered preferable to restore the type of wetland that naturally occurred on the site prior to degradation or destruction. If the restoration site is located in a floodplain surrounded by forested wetland, for example, attempts to restore habitat such as wet prairie may be unsuccessful because of differences in soil types and the likelihood of continual encroachment of forest species into the prairie. Establishing the type of wetland that naturally occurred on the site usually is the easiest and most cost effective plan and generally ensures the greatest chance of success.

Site selection, the process of choosing a specific and appropriate location for the restored wetland, is a vital element of the restoration effort. Although numerous specific factors should be considered, perhaps the most important are various aspects of landscape position, hydrology, and soils. Landscape position greatly affects how a wetland functions; isolated wetlands, for example, function much differently than floodplain wetlands connected by periodic flood pulses (3). Another landscape position consideration is surrounding land use. A potential wetland restoration site surrounded by developed land, or even agricultural ground, is much different than a site bordered or in close proximity to natural vegetation or other wetland, both of which may provide a seed source for vegetation to spread into the restoration naturally. Additionally, a site located along a river or adjacent to other natural habitats is likely to be of more value to wildlife than an isolated site surrounded by urban land.

Hydrology is closely tied to landscape position, and perhaps the most important factor when selecting a wetland restoration site. Hydrology is the driving force behind all wetlands and the presence of wetland hydrology is a necessary component of a successful wetland restoration. Many wetland restorations fail because of a lack of proper wetland hydrology and often this failure is due to an inadequate water supply. However, wetland hydrology does not just involve the amount of water; wetlands are dynamic, fluctuating, high-energy systems that rely on many aspects of water dynamics. Often considered transitional habitats between upland and aquatic systems (3; see Chapter 5), wetlands are periodically, but generally not permanently, inundated with shallow water. These inputs of water could include precipitation, river or stream overflow, surface runoff, or ever groundwater discharge. How water enters a site and how it leaves the site are important aspects of its hydrology. Overall, the general pattern of water flow, including the periodicity, seasonality, depth, and length of flooding or inundation, is of vital importance in determining the potential of a site for restoration to wetland habitat. If adequate wetland hydrology is not present, there is highly limited potential for a successful wetland restoration.

The presence of appropriate soils is an important component of a potentially suitable restoration site. Ideally, restoration efforts seek to minimize excavation and earth moving efforts and thereby take advantage of existing soils present at the site. Since restoration takes place on sites where wetlands previously existed, relatively undisturbed wetland soils, referred to as hydric soils, are often still present. Hydric soils are generally poorly drained soils that readily retain water. Highly permeable or well-drained soils, such as sandy soils for example, generally are not suitable for use in wetland restoration.

Physical construction of wetland restoration sites can often be thought of as reversing the engineering procedure that previously dried the wetland (19). Most restorations aim to restore, at least as much as is possible, the previously existing wetland hydrology to the site. Uncontrolled factors in wetland restoration, such as the damming of a nearby river or the conversion of the surrounding landscape to urban land, are common; however, trying to re-establish natural water flow patterns, including periodic flooding, generally should be a primary goal. The previously existing wetland may have been filled, drainage ditches may have been dug, or berms may have been constructed to block water flow; earth moving, including a final grading of the soil surface to approximate original contour, is required to reverse the effects of such engineering. A common practice throughout much of the agricultural-dominated midwestern United States is the use of below ground tile systems to drain land, including wetlands (see Chapter 5). Illinois is reported to have nearly 10 million acres of artificially drained land, more than any other state (20). Farm ground with a functional drainage tile system often is very desirable for restoration. Typically, all that is required for the return of wetland hydrology is the removal, plugging, or breaking of underground tiles, resulting in a very cost-effective approach to restoration.

Once wetland hydrology has been restored to a site, vegetation establishment needs to be considered. The types of vegetation to be established, for example forested wetland, marsh, or wet prairie, depend on the type of wetland community to be restored. Vegetation may be actively established or it may be allowed to naturally colonize the site. Artificially establishing vegetation by planting or seeding is often an expensive undertaking, especially with large restoration sites. Planting trees, even young ones, can be particularly costly. However, if a forested wetland containing mast-producing hardwoods with high value to wildlife is desired, such as oaks (*Quercus* spp.) and hickories (*Carya* spp.), planting of young trees usually is required. These heavy-seeded species do not readily invade and become established in restorations, as opposed to wind-dispersed species such as maples (*Acer* spp.), willows (*Salix* spp.), and ashes (*Fraxinus* spp.). Trees such as these latter species often readily become established in

wetland restorations, particularly when they are present in nearby natural habitats, even when other woody species are planted. In forested wetland restorations, highly desirable tree species often are planted with the understanding that other common trees will become established independently.

Herbaceous plants often readily establish in new wetland restorations; unfortunately, many of these pioneer species tend to be weedy and undesirable. Although wetland restorations such as marshes sometimes are allowed to revegetate naturally, particularly when adjacent to a similar natural community, vegetation establishment commonly is supplemented. Seeds and seed mixes are readily available from numerous commercial suppliers. Plants such as sedges (*Carex* spp.), asters (*Aster* spp.), and rushes (*Juncus* spp.), as well as many others, are available from seed. Larger perennial wetland plants, such as bulrushes (*Scirpus* spp.), Arrowhead (*Sagittaria* spp.), Pickerelweed (*Pontederia cordata*), Water Knotweed (*Polygonum amphibium*), and Cordgrass (*Spartina pectinata*), often are available commercially as rootstocks or young plants (Fig. 17.1). Seeding and/or planting of desirable wetland vegetation in a new restoration site can accelerate establishment of desirable species and is a hedge against the often inevitable invasion by undesirable species, a major problem in restorations and natural wetlands.

Figure 17.1. Typical wetland plants used in wetland creation and enhancements: a) Pickerelweed (*Pontederia cordata*), b & c) *Carex* spp. (e.g., *C. atherodes* and *C. stricta*), d) Arrowleaf (*Sagittaria latifolia*), e) Bristly Aster (*Aster puniceus*), and f) Water Knotweed (*Polygonum amphibium*).

Even after physical construction and the establishment of vegetation, work is not complete with a wetland restoration. Another important aspect of the process is monitoring and management. Monitoring involves the repeated collection of data over time to see if the wetland is functioning and developing as planned. There is no definite time period as to how long a wetland restoration should be monitored; the Army Corps of Engineers, the principal regulatory agency overseeing wetland restorations across the United States, requires a minimum of five years of monitoring. Wetland restorations typically change rapidly in the first several years, making monitoring and adaptive management vital to the success of the project. Monitoring may reveal issues such as insufficient wetland hydrology, whereby additional earthwork or engineering may be needed to correct the problem. Problems within the plant community are very common and can be detected through monitoring. Poor survival of planted species may require additional replanting. The prevalence of undesirable plant species may lead to management measures, such as herbicide treatment or prescribed burning, to help control the problem. These are but a few examples of why monitoring and management are vital to the restoration process and why they should continue until the restoration appears to be a stable, functioning wetland community. A sound monitoring and management program will greatly increase the long-term chance of success in a wetland restoration, helping to assure that it provides the intended wetland functions and values.

WETLAND MITIGATION—COMPENSATING FOR WETLAND LOSSES

Wetland mitigation is the process by which wetland losses are avoided, minimized, or compensated for. Federal policies during the past decade have increasingly emphasized restoration and creation of wetlands as mitigation for loss of wetlands at other sites. Mitigation has become a cornerstone of the Clean Water Act, Section 404 program, the primary legislative means of wetland protection and regulation in the United States. The concept of mitigation banks also is widely endorsed—creation of wetlands in advance to serve as credits (acres) to be purchased and used by permit applicants when mitigation is required (21). In addition, federal incentive programs, such as Swampbuster and the Wetlands Reserve Program, which are administered by the Natural Resources Conservation Service, encourage wetland restoration and protection on privately-owned, agricultural land (22).

As a result of these programs, from the mid 1980s to the mid 1990s, 180,000 acres of wetland were created or restored in the lower 48 states and, from 1998 to 2004, 349,000 acres were created (22). In 2003, the ACOE issued permits for 21,300 acres of wetland impacts and required 43,400 acres of mitigation (e.g., Fig. 17.2). From 1991 to 2004 in the Rock Island and Chicago Army Corps Districts in Illinois (approximately the northern half of the state), the

Figure 17.2. Wetland loss and degradation due to bridge and road construction in Illinois, an example of a project regulated by the Army Corps of Engineers. Photo by Illinois State Geological Survey.

ACOE issued permits for an average of 260 acres of wetland impacts per year and required 693 acres of mitigation per year (21, ACOE pers. comm.).

While the total number of restored or created wetland acres may be a positive trend, some concerns exist. Wetland protection advocates contend that mitigation may encourage the destruction of wetlands, adverse impacts are not fully mitigated, and that mitigation projects are not adequately monitored or maintained. In 2001, the National Research Council reported that mitigation was not meeting the "no net loss" policy for wetland function and scientists questioned whether it was possible to create wetlands with functions equivalent to those of natural wetlands that have been lost (21). A study of mitigation sites in eight states showed that more wetland acreage was destroyed than created; only 45% of the mitigation sites were successful and less than 55% of permits required site monitoring. The main factor controlling success rate for freshwater wetland restoration is difficulty duplicating wetland hydrology (8). In a study of 128 mitigation sites in the Chicago area, 39% were successful while 52% had excessive water and 9% had insufficient water (3).

Still, successful restoration of wetlands has been demonstrated and the success rate may be improving with time. In a study of five mitigation wetlands in Ohio, 80% were successful, although only 65% of lost wetland acreage was replaced. A study of 6,670 acres of prairie pothole restoration found that, although the sites were generally wetter than the original wetlands, only 20% were hydrologic failures (3).

Most large-scale assessments of mitigation wetlands have focused on whether wetlands were actually created and whether the acreage replaced offsets the acreage lost to development. However, these tallies of acreages convey little about the quality of the mitigation wetlands being constructed. Wetland mitigation efforts should not be measured based on quantity of wetlands alone, but should include some measure of the quality of wetlands that are being constructed. Many ecologists and wetland scientists have been critical of wetland mitigation policies, pointing out that restored and created wetlands may never replace the functions and values of natural wetlands (23, 24). Even if mitigation wetlands are eventually successful, some attributes of constructed wetlands, like soil organic matter content, may take several decades to reach levels equivalent to those in natural wetlands (25). Researchers have measured numerous attributes of mitigation wetlands, including flora, fauna, soils, hydrologic regimes, and nutrient cycling, in attempts to evaluate the progress of wetland restoration projects. However, no standard, acceptable measure of restoration success is available. Often, mitigation success has been evaluated based on a sites' compliance with specific legal requirements. Each mitigation project is required to meet a set of performance standards (measurable objectives), usually within five years of construction, to judge whether the site is legally acceptable. Performance standards are different for each site, but most sites must be wetlands as defined by current federal standards: they must support dominant wetland vegetation and have soils and hydrology characteristic of wetlands. Beyond that, sites often are judged based on characteristics of their vegetation. For example, the Chicago District of the U.S. Army Corps of Engineers recommends performance standards based on the presence of exotic species in a mitigation wetland and the wetland's Floristic Quality Index (26). Swink and Wilhelm (27) developed the Floristic Quality Index as a means of assessing natural areas near Chicago based on the plant species present, and Taft et al. (28) expanded the index for use throughout Illinois

A recent review of 76 mitigation wetlands in Illinois found that most sites at least partially complied with permit conditions (29). Approximately 10% of the sites failed to meet any of their performance standards, 30% partially complied, and 60% complied with all standards. Although performance standards varied widely from site to site, it was apparent that some types of project objectives are not being met. Mitigation projects often failed to restore or create the full area of wetland originally intended for the project. On average, only 70% of the area planned for a project actually met the jurisdictional wetland criteria. This was largely due to a failure to establish sufficient wetland hydrology over the entirety of the planned project area. Mitigation wetlands also often failed to comply with requirements related to the survival of planted vegetation or requirements that dominant plant species should not be exotic or weedy. By the final year in which sites were monitored, 42% of the sites were dominated by at least one exotic plant species, most often Reed Canary Grass (*Phalaris arundinacea*) or Narrow-leaf Cattail (*Typha angustifolia*). Nevertheless, some promising trends were evident. Performance criteria related to the establishment of cover by vegetation or by wetland-dependent plants often were met very rapidly (compare Fig. 17.3a to Fig. 17.3b), and indicators of the quality of plant communities, including the number of native plant species (Figs. 17.4 and 17.5) and the Floristic Quality Index (28), increased over time in most mitigation wetlands. On average they exceeded the levels in natural Illinois wetlands within five years.

Figures 17.3. a: a wetland mitigation site after one year; species composition is dominated by annual wetland plants. b: a wetland mitigation site after four years dominated by perennial species. Photos by A. Plocher.

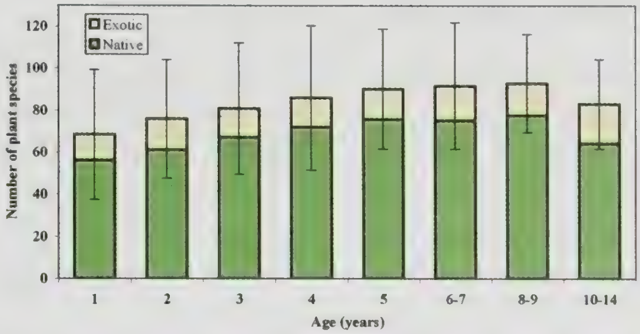

Figure 17.4. Average (+/- standard deviation) plant species richness in 41 Illinois compensatory mitigation wetlands over time, extending to 14 years after establishment.

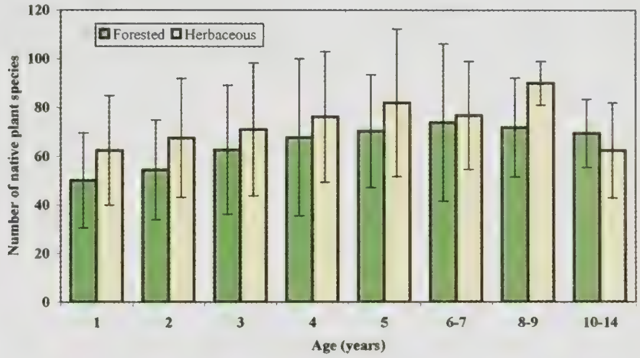

Figure 17.5. Mean (+/- standard deviation) plant species richness in 19 forested and 22 herbaceous compensatory mitigation wetlands over time, extending to 14 years after extablishment.

The ultimate determination of whether a mitigation wetland succeeds or fails depends strongly on the performance standards that are chosen to measure the site's progress. Like most mitigation wetlands elsewhere in the U.S., legal compliance in Illinois has been determined based primarily on vegetation, resulting in a very narrow concept of a site's progress (29). Furthermore, benchmarks for compliance in wetland mitigation projects are often set arbitrarily, without reference to the values of the damaged wetland that is being replaced and with no consideration of what is realistically achievable through wetland restoration or creation. Some performance standards are overly ambitious, perhaps reflecting overconfidence in the ability of human technology to recreate functioning ecosystems. However, if performance standards are too lenient, the result will be an acceptance of low-quality mitigation sites as compensation for wetland damage. In order to truly assess the quality of wetland mitigation projects, we need more information on how and why past sites have succeeded or failed, and we must use this information to define scientifically valid, realistically achievable standards to evaluate the progress of future mitigation wetlands.

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CHAPTER 18

Restoration of Aquatic Communities of Lakes and Streams in Illinois

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OBJECTIVES

Restoration efforts are not confined to terrestrial habitats. This chapter introduces the concept and goals of restoration work being done on aquatic habitats in Illinois. Following national standards for types of restoration projects, types of projects most common on streams, where most projects are located, and how much is being spent on restoration work in Illinois are discussed. In addition, the design, goals, and progress of two-large scale restorations of bottomland lakes along the Illinois River in central Illinois are examined.

INTRODUCTION

With increasing global population growth, the demand for water has grown significantly. As greater access to water has been pursued, the aquatic communities of rivers and lakes have declined and been altered (1). In North America, aquatic communities are estimated to have species extinction rates comparable to those in tropical forests (2). The focus of this chapter is not to review declines in the aquatic systems, but instead to focus upon the efforts to restore the aquatic communities of streams and natural lakes in Illinois. As we shall see, enormous effort is being made to improve the environmental quality of streams and lakes. Indeed, at least some of the effort is contributing to the improved water quality in Illinois, resulting in the recovery of the state's fish fauna (3, 4).

Before continuing we must first address what is meant by "restoration." Broadly speaking, we mean a return to a condition that more closely resembles a historical assemblage of species, including their interactions and functions in a community. The restoration of natural communities is a relatively recent endeavor (see Chapter 12) and as a science, it is still being developed (5). As growth in this field has progressed, various methods have been developed to restore aquatic ecosystems. Within Illinois, how does one apply aquatic restoration methods and set goals for degraded habitats? Given that the landscape of Illinois is highly altered (see other chapters in this volume) and even if all the species could be reintroduced to an area, we must recognize that the return to a historical biotic community found prior to European settlement with an idealized hydrologic and biotic state is unlikely. Indeed, evidence suggests that historic communities cannot be reproduced (6). Rather, if many of the historic species and community functions could be brought back, a restoration should be considered a success.

This chapter will focus upon the actual restoration work being done on lakes and streams in Illinois and is divided into two parts. Part I discusses stream restoration in Illinois and follows recent efforts to categorize and discuss national stream restoration goals and costs as outlined by Bernhardt et al. (7). Part II highlights two large lake restoration projects along the Illinois River in which the authors are participating. Finally, results of these restoration efforts are discussed in a context of future directions for Illinois and other regions of the midwestern United States.

STREAM RESTORATION PROJECTS IN ILLINOIS

Knowledge of past and present stream restoration efforts will help scientists and resource managers to better understand the use of restoration resources and guide better use of limited resources in the future. Fortunately, databases are now available with information that allows comparative analysis of restoration parameters like project goals, funding sources, and monitoring efforts. In particular, the National River Restoration Science Synthesis (NRRSS) has defined and categorized restoration goals across the country (7). These data permit comparison and contrast of stream restoration projects across the United States and among other upper midwestern states (8) with those in Illinois.

Recently, a stream restoration project questionnaire based on the NRRSS database format (7) was distributed by the authors to Illinois resource managers involved with stream restoration. The project questionnaire included stream name, project location, project goals, reach length, funding sources, and cost. Respondent data totaled 19 restoration projects. This survey data plus project data obtained from other sources total 272 projects that were completed from 1990 through 2007 (Table 18.1).

In total, the entire dataset is representative of the variety of Illinois stream restoration efforts that have been

completed in recent years. It contains projects from a variety of funding sources, from urban northeastern Illinois to rural agricultural landscapes across the state, and from early streambank stabilization efforts to more recent dam removal and stream re-meandering projects. Although the survey data accounted for only a small proportion of the total dataset, they contributed information on recent restoration efforts that was more focused towards fish habitat improvement.

A close examination of the data compiled from Illinois resource managers reveals many interesting trends. We discuss these trends in the proceeding paragraphs and put them in perspective by comparing efforts to those being undertaken in other states.

RESTORATION GOALS

Bank stabilization (Figs. 18.1 and 18. 2) was the primary restoration goal in Illinois (N=174) with water quality management a distant second (N=33) and aesthetics/recreation/education ranked third (N=14). Illinois project goal rankings differed somewhat from rankings of other upper midwestern states (8). Instream habitat was the overall top goal in Michigan and Wisconsin, while water quality was the top goal in Ohio. Still, bank stabilization and water quality ranked among the top three goals of those states. Alexander and Allan (8) found that water quality was of greater concern in Ohio whereas Michigan and Wisconsin were more focused on fisheries resources. Illinois is primarily an agricultural state but also has a large urban population. Drainage is an important issue in both urban and rural landscapes and with drainage modification comes increased peak flows and channel instability (9, 10). Bank erosion is also related to water quality through the suspension of soils; hence bank stabilization and water quality are top priorities in Illinois. Many projects may have multiple goals as seen at a project site on Cox Creek, in Cass County (Fig.18.2). At this site, bank stabilization and instream habitat are primary goals but water quality improvement will result from reduced siltation. The instream habitat improvement comprises lunker boxes placed at the base of the eroding bank. The lunker structures provide a deeper stable habitat for larger fishes, particularly game species such as Channel Catfish (*Ictalurus punctatus*) and Largemouth Bass (*Micropterus salmoides*). The riffle area (Fig. 18.2B) provides habitat for smaller fish species such as madtoms and darters.

Interestingly, the aesthetics/recreation/education category was not listed as a top goal nationally, nor in Wisconsin and Ohio (7, 8), but ranked third in Illinois. We attributed this phenomenon largely to a focus on education by state agencies that manage the Conservation 2000 (IDNR) and Section 319 programs of the Clean Water Act (IEPA). Even research-oriented agencies such as the Illinois State Water Survey maintain education as a priority component of their projects. As expected, aesthetics/recreation/education projects were most heavily concentrated in northeastern Illinois where the highest population density is located.

Although bank stabilization and water quality improvement are desired restoration goals, projects that focus on fish species through instream habitat improvement (Figs. 18.1, 18.2, and 18.3), dam removal (Fig. 18.4), or species management are not among the top three goals for Illinois. Instream habitat and fish passage are among the top five goals nationally (7). Instream habitat was also a top priority in Michigan and Wisconsin as discussed above. Perhaps the diminished focus on habitat and fisheries in Illinois reflects a utilitarian view that Illinois streams are primarily drainage conduits and that fish communities are a secondary concern. For example, streambank stabilization with cost-share incentives for landowners is commonly implemented to protect agricultural land from being lost to bank erosion. In these instances there are positive economic returns to landowners over time (11), which accounts for the popularity of those programs. Another perception (albeit unfounded) could be that Illinois streams are so degraded and polluted that there is little hope for fisheries restoration to succeed. Water pollution has been greatly reduced in recent decades and stream fisheries have improved as a

Table 18.1. Data sources for assessment of Illinois stream restoration projects completed from 1990 through 2007. IEPA = Illinois Environmental Protection Agency, NIPC = Northeastern Illinois Planning Commission, IDNR = Illinois Department of Natural Resources, IDOA = Illinois Department of Agriculture.

Program	Funding Source	Implementing Agency (Reference or data source	# Projects	Time Frame
Original Survey	Various	Authors of this chapter (Survey respondents)	19	1990–2007
Section 319	Federal	IEPA (IEPA 2006)	99	1990–2006
Original Survey	Various	NIPC (NIPC 2005)	36	1990–2005
C2000	State	IDNR (IDNR C2000 database)	33	1996–2007
C2000	State	IDOA (IDNR database)	64	1997–1998
Various	Various	IDNR (IDNR database)	21	1997–1998

Figure 18.1. Example of a bank stabilization and in-stream habitat project in northwest Illinois. The wood structure A) is a lunker structure, which creates an overhanging bank for fishes. B) The lunker structure and streambank are stabilized by the addition of rock. Photos by K. Rivera.

consequence. More recently fish passage projects have received greater attention in Illinois. Dam removal and fish passage projects have been successfully implemented (Fig. 18.4) and shown to be cost-effective (Steve Pescitelli, IDNR, pers. comm.)

If aquatic habitat and species restoration are elevated to primary goals, rather than secondary benefits of bank stabilization, restoration of fish communities may be more successful. However, there is little evidence of small-scale instream structures actually benefiting fish populations (12). There are a number of reasons for the failure to demonstrate benefits to fishes including the use of inappropriate structures and failure to address hydrologic and riparian processes in the system (13, 14). Also, such benefits may be real but masked because species-habitat relationships in small streams can be confounded by the dynamic hydrological conditions typical of those systems (15).

Alexander and Allan (8) rightly point out that they assume activities being performed to stabilize banks or modify stream flow are being implemented correctly and are not ecologically detrimental. Bank stabilization does not necessarily translate to restoration of fish communities. In fact bendway weirs (Fig. 18.5) were related to a decline in fish species diversity in the Embarrass River, Illinois (16). A constructed riffle project (Figs. 18.2 and 18.3), on the other hand resulted in a significant increase in fish species richness in Cox Creek. After a review of project activities, we do feel that most of the projects in Illinois are positive with regard to fish communities, or at least are not detrimental. Granted there is little published data to support this belief.

LENGTH OF STREAMS RESTORED

In Illinois the median length of stream restoration efforts was 875 ft (266.9 m) (range 40 – 63,360 ft) (Table 18.2) with a median cost per project of $77,033

Figure 18.2. Example of a bank stabilization and instream habitat improvement project on Cox Creek in Cass County. A) Site before start of project. Note the steep bank and lack of a buffer between the bank and rows of corn. This site has low aquatic habitat diversity. B) Post-construction. The willows on the bank absorb energy generated by water during high flows, thus reducing bank erosion. The lunker structures at the base of the streambank provide a habitat for larger fishes. In the foreground, constructed rock riffles create habitat for riffle-loving fishes and invertebrates.

Figure 18.3. Creation of a riffle on Cox Creek, Cass County. Riffle construction involves the use of heavy equipment and causes temporary disturbance of the site. Photo by J. Rodsater.

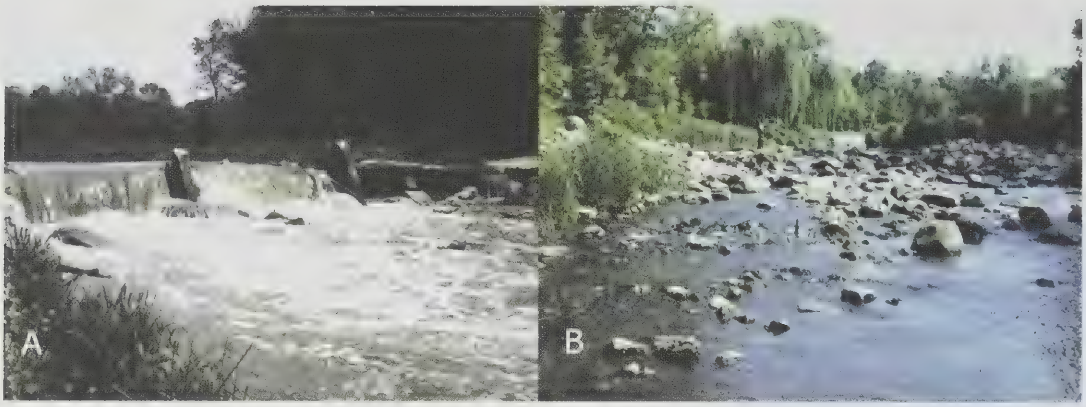

Figure 18.4. Removal of a dam on Waubonsee Creek in Kendall County. Replacement of the dam with a constructed riffle allows fish passage. A) before, B) after. Photos by J. Rodsater.

Figure 18.5. An example of bendway weirs. Note that the weir moves the thalweg (the deepest part of the channel) away from the eroding bank.

(range $2,500 – $1,980,000). The median cost per foot of project length was $88 (range $0.48 – $1,216). The Illinois median restored stream length was 63% shorter than the median from other upper midwestern states (8). Moerke and Lamberti (17) listed stream lengths for an Indiana study of 10 restoration projects in Indiana. From this we estimated that the median length of the Indiana projects was 2,144 ft (662.5 m), a value also much greater than that for Illinois. Moerke and Lamberti (17) however, selected these projects on the basis of greater length and restoration complexity. Length differences among the states may also be related to the kind of projects undertaken. The most common goal for Illinois projects was bank stability with the median length of these projects equaling 600 ft (185.4 m). This value is well below the 875 ft (270.4 m) median stream length for all projects combined. Consequently the relatively high number of bank stabilization projects with lower average stream lengths than other project types likely reduced the median stream length in Illinois. The Streambank Stabilization and Restoration Program (SSRP), the IDOA component of C2000, funded most of the streambank stabilization projects implemented in Illinois in the past 10 years. From 1996 through 2006 the program funded 998 projects treating 94.7 miles of streams and releasing over $6 million in cost-share funds (A. Gulso, IDOA, pers. comm.).

COST OF RESTORATION EFFORTS

Restoration of lakes and streams is a growing activity in the United States and spending is now estimated to be at least $1 billion per year (7). The actual expenditure is probably more because in-kind contributions are excluded and because of the difficulty in obtaining records for projects funded from non-mainstream sources such as local fishing clubs or land developers (8). For Illinois, if we extrapolate using the mean project cost for those projects with reported cost data, the total expenditure for the 272 projects reported herein (Table 18.1) is estimated to be $48,867,988. This substantial amount emphasizes the need to study how the funds are allocated. The highest cost for a single project was for water quality management ($1,980,000) and the lowest ($4,500) was for bank stabilization. Most Illinois projects were funded through C2000 (43%) and Section 319 (36%) programs. The majority of projects were located on private land (60%) versus public land (40%).

The median cost of a project in our Illinois dataset was $77,033, which is nearly six times the $12,957 median value reported for other upper midwestern states (8) and

Table 18.2. Comparisons of mean and median project length and cost per project among midwestern states and the United States.[1]

Region	Project Length (ft)		Project Cost ($)	
	Mean	Median	Mean	Median
Illinois	2,505	875	159,179	77,033
MI, WI, OH[a]	22,598	1,379	189,107	12,957
U.S.[b]	NA	NA	NA	<45,000

[a] from Alexander and Allan (8), [b] from Bernhardt et al. (7). [1] While we do not discuss the means of the project lengths and costs in details, the significantly larger mean relative to the medians does point out that a few projects have high lengths and costs but in reality most projects are much smaller in cost and length.

Table 18.3. Median cost of Illinois stream restoration projects by goal category.

NRRSS Goal Category	Median Cost ($)
Aesthetics/recreation/education (n=5)	36,274
Bank stabilization (59)	53,192
Channel reconfiguration (4)	240,000
Dam removal/retrofit (4)	68,000
Fish passage (1)	5,807
Floodplain reconnection (1)	150,770
Flow modification (2)	109,500
Instream habitat improvement (5)	47,000
Instream species management (0)	-
Land acquisition (1)	1,034,222
Riparian management (5)	159,707
Stormwater management (1)	192,742
Water quality management (7)	412,300

more than 1.5 times the estimated $45,000 median cost nationwide (7) (Table 18.2). Perhaps Illinois' higher median cost reflected in part the greater cost of project planning and implementation in the Chicago region, which is home to over 9 million people and is the largest urban area in the Midwest.

In Illinois the highest total amount of funding for a single category was for water quality (total cost = $3,862,444; median cost = $412,300; Table 18.3). In Ohio, Michigan, and Wisconsin water quality projects also cost the most (median cost = $234,500) (8). The median values in the upper Midwest, and especially in Illinois, greatly exceeded the national median cost of $19,000 (7). Thirty-one of the 33 Section 319-funded projects in our database listed water quality as the primary goal. The goal of that program is to implement non-point source pollution management programs. In Illinois, Section 319 funds have been used to finance approximately 60 mi. (96.5 km) of stream treatments since 1990 (18). The treatments to diffuse pollution sources at the watershed scale and over multiple years are costly to implement (8). The order of magnitude difference between median cost of upper Midwest water quality projects and the national median cost may simply be a result of project scale. Bernhardt et al. (7) listed riparian buffer creation/maintenance as the example of a common water quality management activity. Riparian vegetation management is very inexpensive compared to watershed scale management that comprised the typical Illinois water quality project. Again, the higher cost of projects in urban northeastern Illinois may be at least one factor for higher median cost relative to other upper midwestern states.

GEOGRAPHIC LOCATION OF RESTORATION EFFORTS

Geographically, projects were more concentrated in northeastern Illinois although they were distributed across the state (Fig. 18.6). Sixty-eight of 102

Figure 18.6. Distribution of restoration projects in Illinois since 1990.

counties had at least one project and 34 counties had none. One-third of the more rural counties had no projects and 95% of all counties had less than 10 projects. The Northeastern Illinois Planning Commission (19) identified 129 stream enhancement projects that were implemented throughout northeastern Illinois in the 1990s. Based on this number, the 6-county area (McHenry, Lake, Kane, Cook, DuPage and Will) would average roughly 13 projects/year or 2.5 projects/year for each county. Using summary data from the more rural, agriculture-oriented SSRP, 998 projects were implemented over 10 years statewide for an average of 0.98 projects per year for each of 102 counties. Variation among counties notwithstanding, two to three stream restoration projects are in northeastern Illinois for each project in the rest of the state.

MONITORING OF RESTORATION EFFORTS

Our records indicated a high monitoring rate in Illinois (41%). We considered a project to be monitored if the site was visited at least once to assess the success/failure of the project. Nationally only 10% of stream restoration project records indicated some form of monitoring had occurred (7). Using the NRRSS database, Alexander and Allan (8) noted that only 11% of projects in the upper Midwest study reported monitoring activities. They could not be sure whether the low rate indicated a scarcity of monitoring or a lack of reporting. Upon further investigation of 39 projects in the database, Alexander and Allan (20) reported that 79% reported that monitoring did occur although biological monitoring was generally inadequate.

Alexander and Allan (20) reported the highest monitoring rate for water quality management projects (33%), with monitoring reported on only 4% of bank stabilization projects. They also reported that more expensive projects had a higher monitoring rate, though it was not statistically significant. In Illinois there was no significant statistical difference between the cost of monitored ($165,423) and unmonitored projects ($156,700). Although monitored projects costs are somewhat more expensive, the added cost (assuming the extra cost is attributed to monitoring) seems negligible relative to the gain of knowing if a project was successful or not.

In Illinois the monitoring rate for bank stabilization was 50%. The comparatively high rate was in large part due to inclusion of the IDNR stream remediation database, which documented many bank stabilization project successes and failures based on subsequent field visits. It is clearly important to report and publish project assessments to improve the success rate for future efforts. Bernhardt et al. (7) recommended strategic pre- and post-assessments with standardized methods and have offered the NRRSS database structure and schema to facilitate that effort. The National Nonpoint Source Monitoring Program project in the Blue Creek/Lake Pittsfield watershed (21) is a rare example of a comprehensive study that has greatly improved knowledge of erosion control, sediment transport, and stream channel design techniques in Illinois.

FEDERAL HELP FOR RESTORATION EFFORTS

What do not appear in our dataset are federally funded agricultural programs that may benefit stream systems. The U.S. government invests about $4 billion annually in agriculture conservation programs (22). Alexander and Allan (8) estimated that Natural Resource Conservation Service (NRCS) has contributed $283 million to conservation practices with potential positive impacts to streams (filter strips, riparian buffers, wetlands) in the upper Midwest since 1977. While the benefits of agricultural conservation programs on stream habitat have not been assessed, such efforts are underway (22).

The so-called "set aside" programs such as the Conservation Reserve Program (CRP) and the Conservation Reserve Enhancement Program (CREP) are the most conspicuous of those efforts in Illinois. The newest program, CREP became available for the Illinois River watershed in 1998 and is targeted towards restoring agricultural lands in the floodplain to native vegetation. As a complement to that federal program, the State of Illinois offers additional 15-year, 30-year, and permanent conservation easements. From 1998 through September 2006, the CREP program has restored and or protected 126,016 acres of land in Illinois (D. Bruce, IDNR, pers. comm.). Of that total, 47,504 acres were also enrolled in state easements and 90% were permanent easements (Debbie Bruce, IDNR, pers. comm.). This program has the potential to remediate stream degradation associated with floodplain agricultural land (e.g., higher groundwater, water temperature fluctuation, and sedimentation), and could foster the success of additional restoration efforts in those watersheds.

Another federal/state agricultural program, the Environmental Quality Incentive Program (EQUIP) was recently used to enhance the benefits of CREP in the Spoon River watershed of west-central Illinois. This targeted

Figure 18.7. A typical example of stream bank erosion in Illinois.

effort provided $2.3 million federal dollars and $400,000 of IDNR funds for 39 stream bank stabilization projects to protect CREP acreage from stream erosion (Fig. 18.7) and to decrease sediment inputs and erosion in the Spoon River system (D. Bruce, IDNR, pers. comm.). Coupled with these efforts are sediment and nutrient monitoring in the Spoon River and other select Illinois River tributaries to assess changes that may result from these large-scale programs.

While most of the set aside and related agricultural program information was not available for inclusion in our database, their stream restoration efforts are notable. Alexander and Allan (8) found it impractical to include the extensive NRCS-sponsored stream improvement projects in their study because there was no central data source. Likewise, those data were apparently not included in the NRRSS by Bernhardt et al. (7). We were able to include a total of 80 projects (33% of total) in the dataset that were implemented under the technical guidance of NRCS, due to their cooperation with SSRP. Considering the predominance of agricultural lands in Illinois and the extent of NRCS funding of stream-related restoration, we still consider stream projects in rural Illinois to be under-represented.

As we hopefully have demonstrated above, there has been much recent effort expended towards restoration of streams. Although the successes of those efforts are often subtle and perhaps unnoticed, we think there is cause for optimism. Stream ecosystems are quite resilient and if given a chance they will respond to the various, ongoing restoration efforts. Since implementation of the Clean Water Act in the 1970s there has been a marked improvement in water quality. As a result, we have seen a rebound in fish communities in a number of Illinois stream systems (4). The combination of agricultural conservation programs, watershed-scale management efforts, and habitat restoration efforts of recent years are bound to produce combined benefits to streams. Roni et al. (14) presented a strategy for prioritization of watershed restoration actions. Their recommendations were to first protect existing high-quality habitats then restore connectivity of isolated habitats in the basin. Once connectivity is achieved, the natural hydrologic, geologic, and riparian processes should be addressed. Finally, after the natural processes are restored, instream habitat enhancements could be employed where short-term improvements in habitat are needed. In Illinois we have the framework to implement this process. Nature Preserve and Natural Areas designations protect many of our outstanding stream reaches. Issues concerning hydrologic and riparian processes may be addressed by watershed and agricultural conservation programs. Stream connectivity improvements are being implemented and instream structures have been installed in many reaches. Efforts to focus these efforts on smaller watersheds and monitor the results are also underway. It will require continued diligence for Illinois streams to begin to recover the diversity and productivity present in the early twentieth century.

Figure 18.8. Spring Lake, Mason County, a river-bottom lake of the Illinois River floodplain.

LAKE RESTORATION IN ILLINOIS: TWO CASE STUDIES FROM THE ILLINOIS RIVER VALLEY

A BRIEF REVIEW OF CHANGES ALONG THE ILLINOIS RIVER

Historically, streams dominated the aquatic landscape in Illinois although a substantial numbers of lakes existed in the form of glacial lakes in northeastern Illinois and sloughs and backwater lakes along the floodplains of the large rivers (Fig. 18.8). While many of the glacial lakes remain intact, though impacted by human activities, many of the backwaters and sloughs along major rivers were drained and isolated from their associated rivers. Of the 400,000 acres of floodplain along the Illinois River between La Salle and Grafton, almost 200,000 are kept dry by use of levees, ditches, and pumps (23). For the remaining lakes and ditches, unpredictable water levels, sedimentation, and exotics species contributed to a further habitat degradation (23, 24). Not surprisingly, fish communities along these lakes have drastically declined (5, 25). Restoration of backwater lakes may be the only way for their unique fish communities to survive within the state.

The management focus of river floodplain lakes has historically emphasized flood control, maintaining navigation, and promoting waterfowl hunting. More recent attention has been given to concerns about sedimentation and the resulting loss of hydrological functions of river backwaters and how this affects fish communities. In terms of restoration, efforts along the Illinois River began as early as 1946, not long after the last levees were constructed in the 1920s (26). At that time, the removal of some levees was being considered primarily as a means to reduce flooding in other areas of the river valley. Improved hunting and fishing were thought to be secondary benefits (26). Early proponents of establishing areas to improve wildlife conservation and stewardship in bottomland lakes include Bellrose and Rollings (27). These INHS scientists estimated that public wildlife and fishery values were greater than private values such as agricultural uses in bottomland areas. Starrett (28) provided a similar estimate for fishing at Chautauqua Lake,

currently one of the largest floodplain lakes along the Illinois River in Mason County. Both studies used economic reasons to promote conservation of these areas. The protection of these areas now relies less on economic arguments and more on protection of species, game and non-game alike, or other values such as broader environmental services.

CASE EXAMPLES – TWO ONGOING ILLINOIS RIVER PROJECTS

The guiding principles of the case studies discussed in the proceeding paragraphs are the control of the Common Carp (*Cyprinus carpio*) (Fig. 18.9), reintroduction and promotion of native species of plants and animals, and control of the water levels. To follow the guiding principles, a general set of methods is used in both case studies. However, each restoration is unique and exact methods employed reflect the particular set of problems at each lake. Although the general methods are briefly discussed here, some of them are discussed in greater detail within each case study. Note that many of the methods employed, especially in the application of rotenone and reintroduction of uncommon species, are novel. In both cases, adaptive management was and continues to be required for continued success.

Restoration of the bottomland lakes requires elimination or at least strict control of Common Carp, Grass Carp (*Ctenopharyngodon idella*), and now, the Asian carps (*Hypophthalmichthys* spp.) (Fig. 18.10). The Common Carp and Grass Carp have a high impact on the vegetation and indirectly on the stability of the substrate (29). The Asian carps are believed to be serious competitors with some of our native species such as the Paddlefish (*Polyodon spathula*) (see Chapter 11 and Fig. 9.9). The general method of control is removal by the use of rotenone that requires expert knowledge of application. As rotenone will remove all the fish species, considerable effort must be made to restock the lake with species native to the area and habitat. Common species such as Largemouth Bass are easily obtained in large numbers and stocked. However, many of the species are nongame and the local populations offer only limited quantities. Selection of fishes to be stocked and how they are stocked is emphasized in the second case study at Emiquon National Wildlife Refuge.

Control of water levels is also central to maintaining the plant and animal communities. While the communities were connected to Illinois River through flooding, the unstable hydrology outside of the restoration areas has necessitated maintenance of levees and other water-control devices. Although the use of levees seems counterintuitive to the achieving restoration goals, they do isolate the lakes from an influx of Common Carp, Zebra Mussels (*Dreissena polymorpha*), and other exotic species. Sudden changes in water levels can drastically disrupt life cycles of both plants and animals. Alternatively, reduction of the annual cycle of rising and falling water levels may also disrupt life cycles as many of the species are adapted to such cycles.

Example #1: Spring Lake, Tazewell County — 30 years of restoration and management

Most bottomland lakes in the middle Illinois River valley were characterized before the mid-1950s by broad shallow basins and abundant aquatic vegetation (25). Marshlike conditions prevailed with diverse fish populations characterized by excellent growth and condition. However, during the period of 1938–1976 the bottomland lakes in this region lost most of their macrophyte (large aquatic plants) populations except for those with species tolerant of the changed hydrology, high turbidity, and soft substrates.

Figure 18.9. INHS fisheries biologist holding two large gravid Common Carp. Each female will lay thousands of eggs every spring. Photo by E. Gittinger.

Although it is difficult to know for sure, the Common Carp is thought to have initiated openings in bottomland lakes by destroying the macrophytes (pers. obvs.) Decreasing water clarity brought on by wave action and increased sediment loads in the adjacent Illinois River and subsequently deposited in the lakes increased and maintained this loss of aquatic vegetation. The continual presence of Common Carp (see Chapter 11) has accentuated the influence of wave action and sedimentation introduced from the river (23). In addition, waterfowl management techniques were altered to provide food for migrating waterfowl. On most of the former bottomland lake-marshes, this meant building water control structures to enable the manager to de-water the lakes in early July, plant moist soil monoculture crops such as millet (*Echinocloa* sp.) and Buckwheat (*Fagopyrum esculentum*), and then re-water in late September. Large floodplain lakes in central Illinois such as Chautauqua Lake, Rice Lake, Clear Lake, and Big Lake as well as others were thus altered and fish population diversity and survival at these locations has been severely impacted by this management procedure (25).

Spring Lake, a state-owned lake in central Illinois, offers a prime example of the cascading changes that occurred to habitats in Illinois River floodplain (Figs. 18.8 and 18.11). Spring Lake is a lateral oxbow of the Illinois River and currently covers 1,188 acres (480.78 ha). This elongated lake lies immediately adjacent to the Illinois River floodplain bluff in southwestern Tazewell County. The Spring Lake Drainage District that borders Spring Lake on

Table 18.4. Fish diversity of Spring Lake, Tazewell County, Illinois, from three time periods. X = species presence; source IDNR district files.

Common Name	Scientific Name	1961	1977	2007
Spotted Gar	*Lepisosteus oculatus*			X
Gizzard Shad	*Dorsoma cepedianum*	X	X	X
Common Carp	*Cyprinus carpio*	X	X	X
Golden Shiner	*Notemigonus crysoleucas*	X	X	X
Emerald Shiner	*Notropis atherinoides*	X		X
Bigmouth Shiner	*Notropis dorsalis*	X		
Bluntnose Minnow	*Pimephales notatus*	X	X	X
Fathead Minnow	*Pimephales promelas*			X
White Sucker	*Catostomus commersoni*		X	
Lake Chubsucker	*Erimyzon sucetta*	X		
Bigmouth Buffalo	*Ictiobus cyprinellus*	X		
Black Bullhead	*Ameiurus melas*	X		X
Yellow Bullhead	*Ameiurus natalis*	X	X	
Brown Bullhead	*Ameiurus nebulosus*	X	X	X
Channel Catfish	*Ictalurus punctatus*	X		X
Central Mudminnow	*Umbra limi*			X
Grass Pickerel	*Esox americanus*	X	X	X
Northern Pike	*Esox lucius*		X	X
Muskellunge	*Esox masquinongy*		X	
Starhead Topminnow	*Fundulus dispar*	X		X
Blackstripe Topminnow	*Fundulus notatus*	X		X
Mosquito Fsh	*Gambusia affinis*	X		X
Brook Silverside	*Labidesthes sicculus*	X	X	X
White Bass	*Morone chrysops*		X	
Yellow Bass	*Morone mississippiensis*	X	X	X
Largemouth Bass	*Micropterus salmoides*	X	X	X
Green Sunfish	*Lepomis cyanellus*	X	X	X
Pumpkinseed	*Lepomis gibbosus*	X		
Warmouth	*Lepomis gulosus*	X	X	X
Orangespotted Sunfish	*Lepomis humilis*	X		
Bluegill	*Lepomis macrochirus*	X	X	X
Redear Sunfish	*Lepomis microlophus*			X
Redspotted Sunfish	*Lepomis miniatus*	X		
White Crappie	*Pomoxis annularis*	X	X	X
Black Crappie	*Pomoxis nigromaculatus*	X	X	X
Sauger	*Sander canadensis*		X	
Walleye	*Sander vitreus*		X	X
Yellow Perch	*Perca flavescens*	X	X	
Logperch	*Percina caprodes*		X	
Freshwater Drum	*Aplodinotus grunniens*	X	X	X

the west was organized in 1904. The district constructed the river levee by 1916, effectively separating Spring Lake from the Illinois River.

Prior to 1959, Spring Lake consisted of a narrow, elongated body of water with an average depth of 4.1 feet and an area of approximately 632 acres (255.8 ha). Water clarity at that time was very high due to its narrow configuration, which assisted in minimizing wind action and suspensions of sediments. In 1959, levees were raised three feet at Spring Lake resulting in a doubling of acreage to 1,285.0 acres (518.8 ha). Raising the levees created a larger expanse of open water that significantly increased wind sweep and wave action, resulting in constant re-suspension of fine silt particles and a decline of aquatic vegetation. In addition, the Common Carp population eliminated macrophytes and contributed to the loss of spawning habitats and cover for young-of-the-year game fish species. These conditions remained until 1978 (unpublished IDOC Division of Fisheries files). After this change in water level, native species diversity fell from 25 species in 1961 to 19 species in 1977, just before the first attempt to remove Common Carp from the lake (Table 18.4).

During the 1970s, the Illinois Department of Conservation (now the IDNR) determined that the thrust of both fishery and waterfowl management at Spring Lake would be based on the redevelopment of the lateral marsh condition once so abundantly present along the middle Illinois River basin. In order to achieve this goal, water control structures were built in 1977 (Fig. 18.12) to effectively separate the lake into two segments: a north unit of 578 ac (233.9 ha.), and the south unit of 610 ac (246.9 ha.) (Fig. 18.8). This separation allowed individual management and rehabilitation of each unit.

To increase re-vegetation potential, the first step of restoration targeted the removal of Common Carp. To do this removal, a rehabilitation attempt was made on South Spring Lake at full lake volume in September of 1977. A total of 1,150 gallons of rotenone (2 ppm) were applied over a period of two days utilizing bailers on four boat units as well as water pumps and backpack sprayers in seep areas. Many adult Common Carp survived this treatment and were able to establish a huge year-class of young fish. It was subsequently hypothesized that the effort was negatively influenced by elevated water temperatures and high water recharge levels from springs.

After the unsuccessful rehabilitation attempt in the fall of 1977, plans were made to de-water the South Spring Lake unit and treat it with rotenone after most of the large spring discharge areas were exposed. Researchers thought that lower water levels would reduce the number of areas that the Common Carp could use to avoid the rotenone. In the July of 1978, South Spring Lake was drawn down approximately 3.6 ft (1.1 m) below normal levels by opening the spillway structure. In September 1,280 gallons of rotenone were applied to the drawn-down lake, resulting in a dosage rate of 60 ppm. As rotenone was applied, the spillway was closed and the lake began refilling immediately. The resultant refilling of the basin allowed for optimal waterfowl use of the natural moist-soil plants that had become established on the extensive mud flat area.

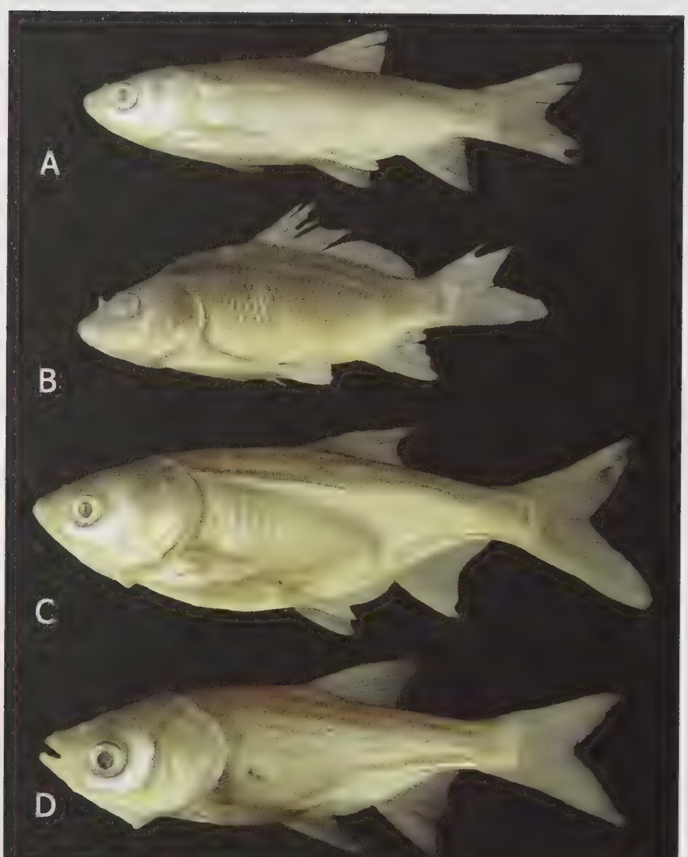

Figure 18.10. The four Euroasian carp species established in Illinois. A) Grass Carp (*Ctenopharyngodon idella*), B) Common Carp (*Cyprinus carpio*), C) Silver Carp, (*Hypophthalmichthys molotrix*), D) Bighead Carp (*Hypophthalmichthys nobilis*). These individuals are preserved juveniles less than six inches in length.

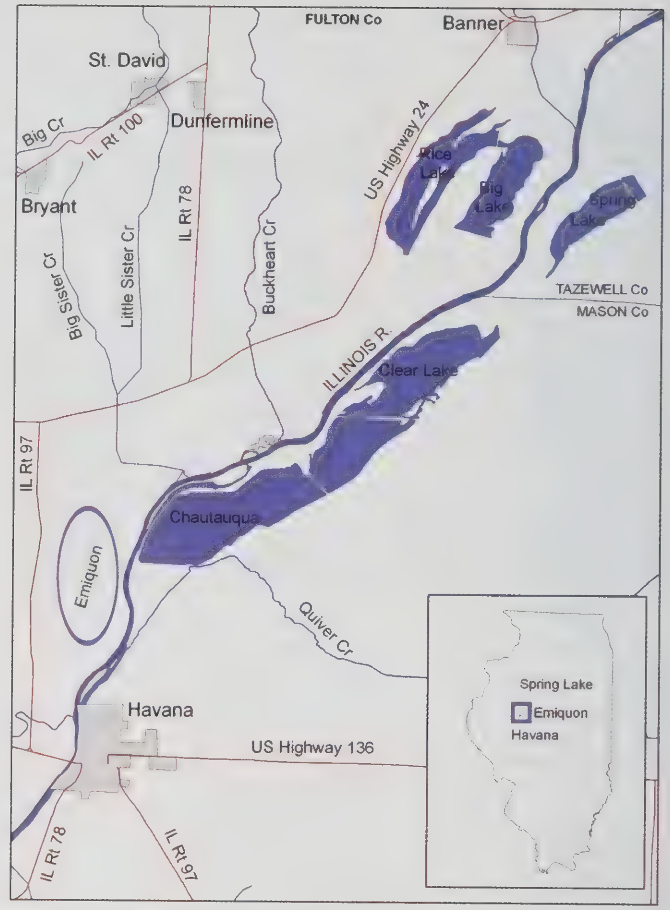

Figure 18.11. Map of the location of Spring Lake and Emiquon in central Illinois.

Although survival of Common Carp was minimal compared to the initial attempt at rehabilitation in 1977, they were able to survive in numbers sufficient to repopulate the lake with their initial spawn in 1979. The reasons for this second failure were multi-fold and that reduction of water levels was not, in itself, sufficient to guarantee success. These reasons included: small areas of underwater springs remained after drawdown, offering refuge to Common Carp; warm water temperatures and a phytoplankton bloom at the time of treatment resulted in rapid detoxification of rotenone; and the application of rotenone by fixed wing airplane with droplet size settings too small and pressure too high resulted in atomization of rotenone and detoxification by atmospheric oxygen.

The 1978 restoration effort in South Spring Lake was more successful than those conducted the previous year, however the success was short-lived. Some aquatic vegetation such as Curlyleaf Pondweed (*Potamogeton crispus)*, American Elodea (*Elodea canadensis*) and Sago Pondweed (*Potamogeton pectinatus*) were re-established in late spring and early summer months. This initial result was significant given that aquatic plants had not been found in Spring Lake since 1965. Unfortunately, a subsequent and rapid decline of aquatic vegetation occurred, most likely due to wind sweep, wave action, and turbidity increases caused by the rapidly expanding Common Carp population.

Given the lack of long-term success on South Lake, it was determined that the next rehabilitation effort

would take place on North Lake using a new strategy to remove undesirable fishes. This strategy would utilize winter kill conditions in which lower dissolved oxygen and water temperatures lead to higher fish mortalities and use multiple rotenone application methods, some of which were untested. The target date for North Spring Lake was set for mid-March of 1981 because historical data identified the end of the first week of March as the average date of ice melt at Spring Lake. As a preliminary step, a drawdown was begun in August of 1980. This resulted in water surface acreage being reduced by half and left in a de-watered state during the winter of 1980–1981. A problem identified in the previous attempt to rehabilitate the south unit was difficulty in maintaining rotenone toxicity in areas of heavy spring flow. To address this issue and prior to the initiation of treatment, spring discharge areas were first identified visually from the air and by temperature probes placed in suspected areas during the 1979 field season. These efforts identified seep springs and large discharge areas. Secondly, a novel application method for rotenone was designed. Several thousand pounds of seasoned hardwood sawdust were to be dried and placed into canvass bags with sand (for weight). The sandbags would be tied and placed in a stock tank and a 2% solution of rotenone would then be added to the tank, allowing the overnight absorption of rotenone by the sawdust. These bags could then be precisely placed in areas of high-water discharge.

Figure 18.12. The control structure between North and South Spring Lakes under construction.

Ice-out in the drawn down North Spring Lake occurred on March 5, 1981 and the application of rotenone was performed on March 15 by the aerial application from a helicopter (Fig. 18.13A). Fourteen hundred gallons were applied, resulting in an overall dosage of 17 ppm; a lighter dosage than used in previous attempts. In addition to the aerial application, on the next day, the sawdust bags that had been soaking in rotenone were loaded in foot tubs and dropped from low level out of a helicopter, directly into the mouths of the larger springs and in the identified seep areas. Rotenone immediately began to leach from the sandbags into the spring discharges and could be visually observed by the milky appearance of the rotenone carrier (creosote) (Fig. 18.13B). On March 17, several over-flights by helicopter identified persistent areas of turbidity (turbidity presumably indicating Common Carp) in confined areas. These areas were subsequently treated using sawdust bags and by dropping pint Ziploc bags loaded with rotenone from the helicopter. Some limited application of rotenone was also accomplished using boats and boat bailer applicators as well as backpack sprayers on mud flats. The combined efforts resulted in the removal of 19 species of fishes (30).

In order to ascertain the effect of the rehabilitation, North Spring Lake was sampled in September of 1981. Even with the extreme measures taken to eradicate them, Common Carp were able to achieve reproduction and recruitment. The source of these fish was thought to be an adjacent small private lake and/or stocking of breeders by unknown individuals. To counter this development, large numbers of breeder Largemouth Bass were stocked into the Lake. These efforts resulted in a very strong year class of bass.

Figure 18.13. A) A helicopter was used to spray rotenone in lowered lake to remove the fish population. B) The seep area of Spring Lake. The whitish area in the lower center of picture is the creosote mixture that disperses the rotenone.

Even though Common Carp persist in North Spring Lake to this date, abundant Largemouth Bass and small Bluegill have been able to adequately control carp reproduction and recruitment through predation.

Because of this rehabilitative effort, the aquatic plants responded in abundance. Coontail (*Ceratophilum desmersum*), naiads and pondweeds responded with vigor and rapidly covered 75% of the lake. Transparencies increased rapidly to average from 3.3 to 4.9 ft. (1 to 1.5 m). Coontail is now very abundant and usually occurs in dense stands as an understory below American Lotus (*Nelumbo lutea*) and Common Water Milfoil (*Myriophyllum sibiricum*). Common Water Milfoil and Coontail, the two most abundant aquatic plants in Spring Lake are reported by Engel (31) to harbor macroinvertebrates and to provide protective cover for juvenile gamefish and small fish species.

As a result of the successful techniques utilized in rehabilitating North Spring Lake, a rehabilitation of South Spring Lake was targeted in spring of 1986. The same methods and techniques were selected for use in South Spring Lake including aerial application in cold water, draw-down of water levels, and slow discharge of chemicals in spring areas. A mid-summer reproduction check and a major fall population survey failed to detect any carp survival after the rehabilitation. Aquatic plant growth during the year was exceptional and resulted in marshlike conditions. The lake was restocked and considered to be restored according to the original goals of the Illinois Department of Conservation. In addition to native species of fishes being reintroduced, waterfowl have also benefited from the extensive vegetation growth.

At present, the restoration efforts in Spring Lake appear to have succeeded. A total of 33 fish species native to North America are now present in North and South Spring Lakes (Table 18.4). A few species, such as the Muskellunge (*Esox masquinongy)* were unlikely to have occurred in Spring Lake historically but are present for fisheries management reasons. More importantly, a diverse functional community has been established and has remained stable since the 1980s including species that have declined significantly in Illinois such as the Starhead Topminnow (*Fundulus dispar)*, Central Mudminnow (*Umbra limi*), and Brown Bullhead (*Ameiurus nebulosus*) (4). It may be that in the future, these species and others will be spared from further decline in Illinois by restoration efforts similar to the Spring Lake project.

Example #2 - Emiquon, Fulton County – A work in progress

Emiquon National Wildlife Refuge in Fulton County is located near Spring Lake (Figs. 18.10 and 18.14) but on the west side of the Illinois River. Emiquon contains two lakes of historical note: Thompson and Flagg lakes (see 32 for an excellent history of this area). The original lakes were important hunting and fishing areas to local inhabitants. However, in the 1920s, levees were built to prevent flooding from the Illinois River and the lakes were drained. The largest floodplain lake along the Illinois River, Thompson Lake, disappeared and a critical fish and wildlife habitat was gone. Fields were created for row cropping and a system of ditches and pumps installed to prevent ground and surface water from encroaching onto the fields.

The Nature Conservancy (TNC) purchased the lakes and surrounding areas in 2000 for the purpose of restoration. This project is notable for two reasons. First is its size. There are few examples of floodplain lakes systems of this size undergoing plant and animal restoration (24). The total area of the TNC holding is 7,500 acres (32). Secondly, the area was studied long ago by INHS scientists such as S.A. Forbes, R.E. Richardson, and C.A. Kofoid (32). Because of these historic biological data, we have a set of possible restoration goals to achieve. The types of plants and animals that once occurred at Emiquon, or in the surrounding area, have become biotic candidates for species reintroduction.

Although it has been roughly 60 years since the first studies of the conversion of Emiquon to a conservation area, the levees remain in place keeping it separated from the Illinois River. Much of the environment along the entire river has changed over the last 100 years. Ideally, the area would be reconnected to the river to restore the natural hydrological pulses. However, a number of problems remain to be considered before a reconnection to the river can be made (32). Increased river elevation and altered hydrology have altered the plant and animal communities all along the river (24, 33). If the river were to be reconnected to the floodplain, how will invasive plants and animals affect the restoration? While a reconnection may re-establish a natural flowing regime, sediments, water levels above historical norms, and invasive species may produce communities of non-native species that function in very different and unanticipated ways. Such results would produce a community not envisioned by TNC and other parties involved in the restoration project.

Currently, the levees remain and restoration is underway at Emiquon. Farming operations have ceased and water levels are being allowed to rise. Flag and Thompson lakes are being allowed to fill again for the first time in 80 years. Originally, Flag and Thompson lakes were separated

Figure 18.14. Photo of Emiquon Lake taken in November 2008. Photo by M. Retzer.

by low natural levees. Now, they are connected by sizable ditches and probably by field tiles. Such connections allow fishes to easily pass between the two lakes.

Beginning in 2007 and extending over a three-year period, native fish reintroductions at Emiquon are taking place. The goal is to establish several fish species at the site and to begin rebuilding the native fish community, including functions that they provide to the wider aquatic community. There have been few, if any, attempts to do this type of restoration project at this large a scale. In addition, few introduction projects are financially supported for this length of time.

Figure 18.15. The Bowfin (*Amia calva*) one of the species being reintroduced to Emiquon. Note that the green color indicates that this specimen is a male in breeding condition.

Prior to the reintroduction of native fishes, a review of literature was conducted and discussions were held among the participants to establish a list of potential species of fishes for stocking. This list identified 37 species that primarily inhabit floodplain lakes in the area, and represented various trophic levels and a wide array of fish families, and contained species that would also support fishing opportunities. With these criteria a basic functional food web could be established and subsequently expanded in the future.

Before the restocking of native fishes into Emiquon could proceed, two additional obstacles needed to be addressed. Although the lakes had long been drained, an extensive network of drainages ditches remained that contained Common Carp and Grass Carp. In order to start with a proverbial clean slate, these fishes needed to be removed before the lakes could be re-established. During spring of 2007, the application of rotenone by spraying and slow release devices was used to accomplish this goal. Thus far in late 2008, these fishes have not been detected using a variety of sampling methods (e.g., traps, dipnetting, electroshocking, snorkeling).

The second obstacle was to find local stocks of the various species, which perhaps were once widespread but may now be limited to isolated populations and to obtain enough stock material for establishing the species without impacting the source population. In addition, stocking of large predatory fishes could seriously threaten smaller 18.species being stocked in low numbers. Predators such

Table 18.5. Summary of the species stocked into Thompson Lake, Emiquon, Fulton County, Illinois and locations of stocking. M = main lake, ID = isolated ditches, B = borrow pit in 2007.

Species	
Black Crappie (*Pomoxis nigromaculatus*)	M
Blackstripe Topminnow (*Fundulus notatus*)	M
Bluegill (*Lepomis macrochirus*)	M
Bowfin (*Amia calva*)	ID, M
Brook Silverside (*Labidesthes sicculus*)	M
Brown Bullhead (*Ameiurus nebulosus*)*	M
Central Mudminnow (*Umbra limi*)	ID
Channel Catfish (*Ictalurus punctatus*)	M
Golden Shiner (*Notemigonus crysoleucas*)	M
Johnny Darter (*Etheostoma nigrum*)	M
Lake Chubsucker (*Erimyzon sucetta*)	ID
Largemouth Bass (*Micropterus salmoides*)	M
Logperch (*Percina caprodes*)	B
Mud Darter (*Etheostoma asprigene*)	B
Orangespotted Sunfish (*Lepomis humilis*)	M
Pirate Perch (*Aphredoderus sayanus*)	ID
Pumpkinseed (*Lepomis gibbosus*)	B
Spotted Gar (*Lepisosteus oculatus*)	M
Starhead Topminnow (*Fundulus dispar*)	ID
Tadpole Madtom (*Noturus gyrinus*)	B, M
Warmouth (*Lepomis gulosus*)	M
Walleye (*Sander vitreus*)	M
White Crappie (*Pomoxis annularis*)	M

*Brood stock also placed into off site pond.

Figure 18.16. Field biologists collecting wild-caught fishes in Crane Creek, Mason County for stocking in Emiquon. A backpack shocker and dipnets are being employed to catch specimens.

Figure 18.17. A nursery ditch at Emiquon, Fulton County. The blue circle indicates a drainage tile. Photo by R. Hilsabeck.

as the Bowfin (*Amia calva*, Fig. 18.15) were emphasized to control potential Common Carp and Grass Carp populations. Beginning in spring of 2007, habitats within the Illinois River valley were sampled for stocking material. One creek in particular, the Crane Creek system in Mason County (Fig. 18.16), accounted for eight species. Big Lake, north of Emiquon, was a source for several more species. For several of the species, less than 50 individuals could be transplanted. This stocking rate is quite small for a site that will reach 1,500 acres or more at high water levels during spring. Hence, smaller species are being placed in isolated nurseries to build larger populations for direct stocking into Thompson Lake. These nurseries were in the form of three isolated ditches and one burrow pit (Fig. 18.17).

In 2007, 23 species of fishes (Table 18.5) have been stocked into either a nursery habitat or Thompson Lake. The number of individuals stocked in 2007 varied greatly. For example, 4,320 Walleye brood fish were stocked and only 11 Tadpole Madtoms (*Noturus gyrinus*) (R. Hilsabeck, IDNR, pers. comm.). In fall of 2007 the assessment of stocking success and reproductive success of stocked adults was initiated. Presence of young of year shows evidence of reproduction for the Starhead Topminnow and Lake Chubsucker (*Erimyzon sucetta*) in the nursery. In 2008, sampling of the main lake area by INHS, IDNR, and TNC staff using standard techniques has found at least six species present and reproducing: Bowfin, Largemouth Bass, Black Crappie (*Pomoxis nigromaculatus*), Warmouth (*Lepomis gulosus*), Bluegill (*Lepomis macrochirus*), and Pumpkinseed (*Lepomis gibbosus*, Figure 18.17). As future stockings are planned through the summer of 2009, it is hoped that the total number of established species will continues to rise.

The assessments have revealed the many challenges to large-scale, aquatic restoration. For instance, although a ditch was treated with rotenone (Fig. 18.17), a few Mosquitofish (*Gambusia affinis*) survived. The ditch became the nursery for the Starhead Topminnows. The topminnows reproduced but not with the expected success. Their reproduction was likely suppressed by the Mosquitofish through competition or direct mortality of young topminnows. This phenomenon was observed between Mosquitofish and other species of topminnows (*Fundulus*) (34). In this case, with predators eliminated from the ditch, the Mosquitofish population increased to very high densities. Obviously, interactions of the fishes being introduced must be given some consideration, and they add to the difficulty of establishing native fishes.

Working with large complex systems requires flexibility and the ability to adapt to a constantly changing environment. In summer of 2007, Emiquon experienced an extreme drought. The water level fell significantly and two of the isolated ponds containing stocked fish dried completely. Then heavy rains in 2008 led to very high water levels that connected the nursery areas directly to the main lake. In addition, low water levels revealed the extensive nature of the interconnection of the ditches with each other and the reconstituted Thompson Lake. The interconnection comes in the form of tiles and culverts (Fig. 18.17). In the process of stocking target species or removing undesirable species (e.g., Common Carp), this subterranean network provides a way to avoid rotenone applications and can allow predators access to areas stocked with vulnerable species. It will require additional efforts to isolate small nursery areas and/or time to evaluate the roles these connections play in the hydrology of the system.

Figure 18.18. The Pumpkinseed (*Lepomis gibbosus*), an example of one of the sunfish species being stocked into Emiquon.

Annual sampling assessments are planned to determine the success of original stocking efforts and the reproductive success of stocked fish species. While it is too early to draw definite conclusions in year one of a three-year project, evidence of stocking success and survival of some of the species is positive. As of fall 2008, aquatic vegetation in the system is becoming abundant and providing the fishes with critical habitat.

SUMMARY

The restoration of non-wetland (see Chapter 17) aquatic habitats for the benefit of native fish and wildlife has been ongoing in Illinois for over 30 years. A review of stream restoration efforts reveals that over $45 million has been or will be spent on 13 different types of projects. Interestingly, the majority of projects were located on private land (60%) versus public land (40%). Bank stabilization was the primary restoration goal in Illinois with water quality management a distant second and aesthetics/recreation/education ranked third.

There is a long history of habitat alteration along the Illinois River, mostly the draining and isolating of sloughs and backwater lakes in its floodplain. More recently, two lakes, Spring Lake and Thompson Lake at Emiquon, have been or are being restored to a condition resembling their original states. Work on Spring Lake began in 1978 and involved several attempts to eliminate the Common Carp from the system, using in some cases novel application methods, and to establish a sustainable fish and plant community. Efforts appear to be successful as a diverse fish community at the site is currently stable. At Emiquon, efforts are currently underway to re-establish the fish community. Twenty-three species have been stocked into the lake and six species are known to be reproducing in the lake at present.

Given the ever increasing World and U.S. populations, demands on natural resources will continue to rise. The restoration of once-altered habitats is one avenue of offsetting those demands. With its high level of alteration (see other chapters in this book), the past and present restoration of aquatic habitats in Illinois can provide valuable information for future efforts. Data in this chapter indicate that significant effort is being made to restore streams in Illinois but fish communities are not the primary targets of most projects. Although many projects are being monitored, results of the success for most of the projects remain to be determined. However, increased fish diversity has been noted at one site on Cox Creek. Even if all the projects are monitored, there remains a need to summarize and disseminate information on what projects were or were not successful. Two large bottomland lake restoration projects have demonstrated that, if turbidity can be reduced and aquatic vegetation established through control of Common Carp, rich and historic fish communities can be reestablished with continual management. In total, these results provide hope that the successful restoration of aquatic habitats can be obtained in regions where land-use patterns have been overwhelming altered.

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CHAPTER 19

Perched in the Catbird Seat for the Next 50 Years: A Future for Natural Resources and Natural Resource Agencies

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OBJECTIVES

This chapter explores future landscape trends and examines how natural resource conservation and science may change in response to developing technologies, multidisciplinary approaches, and their interaction in a continuously changing landscape and constituency. The work of the Illinois Natural History Survey will continue to evolve accordingly over the next 50 years as it responds to the needs of the agencies, organizations, and members of the public that depend on it for sound conservation science. In this way, INHS will continue to serve as a model for other agencies charged with providing data utilized for sustainable management of natural resources.

INTRODUCTION

When the Illinois Natural History Survey celebrated its 100th anniversary in 1958, Harlow Mills, then INHS Chief, discussed the future for the Survey from his perspective in the mid-twentieth century.

> *A half century ago [Stephen A.] Forbes wrote, 'I shall be governed by the reflection that we are today looking forward and not back---that we are preparing for the future and not studying the past---…'. The same fresh view should govern us at the end of 100 years. The problems in nature are ever changing, or, rather, our needs from and approach to nature are ever changing. There are new demands and new approaches. New research techniques require re-evaluation of what has been done. In agriculture there are new crops and new methods of raising them. New plant diseases appear. New insect pests invade the state. New demands are made for recreation. New advances in pure scientific knowledge must be made. All of these demands and approaches require the attention of the research specialist. All are inextricably bound up in the future.*(1)

Mills's comments remain pertinent today, although the rate of change has almost certainly increased dramatically. The previous chapters in this book have documented various trends that affect natural resources both positively and negatively, but mostly with a focus on the past. This chapter looks forward, predicting the future of natural resource conservation brought about by changes in the landscape, in the constituents for natural resource management, and in conservation science. The emphasis will be on Illinois and the Midwest, but most of the patterns will likely hold nationally and globally.

FUTURE LANDSCAPE TRENDS

Past human impacts on the environment have been well documented. It is certain that people will continue to modify their surroundings. Following are 10 general and widespread trends that likely will be of particular importance. Most of these will result in continued degradation, but three offer hope of recovery.

THREATS

Habitat Loss and Fragmentation—Projected trends suggest that human populations will continue to grow and to shift from rural to metropolitan areas. In the United States, including Illinois, not only will the number of people continue to grow, but the amount of space required to accommodate that growth will increase disproportionately. For example, the population of the Chicago metropolitan area increased by 4% between 1970 and 1990, while the amount of land in urban uses increased by 33% during the same period (2). This resulted in the conversion of over 450 square miles of agricultural and vacant lands to residential and employment uses (2), a pattern that continues (3). This growth around large and small cities is further reducing and fragmenting habitats. Table 19.1 summarizes some of the declines in native habitats and species in the United States.

Table 19.1. How U.S. wildlife species and habitats are doing (adapted from 7).

- About 33% of U.S. native plant and animal species are at risk of extinction
—37% of fresh water species
—19% of forest species
—18% of grassland and shrubland species

- Wetlands, riparian areas and aquatic habitats have shown evident declines
—the area of freshwater wetlands in the US. has decreased by 9% since 1955
—about 62% of the freshwater plant communities in wetland and riparian areas considered at risk

- Forest area has not changed significantly since 1953. Forest composition, however, has changed dramatically.

- Grasslands and shrublands have declined by about 170 million acres since European settlement, a loss of about 20%.

Human/wildlife conflicts—Increased expansion of metropolitan areas will also bring wildlife, domestic animals, and humans into more frequent contact, leading to a variety of problems (Fig. 19.1). Vehicle collisions with deer likely will increase, as will confrontations between humans, pets, and large mammals including predators such as coyotes, cougars and bears. Increased spread of diseases among wildlife, domestic animals, and humans is also expected.

Energy—Demands for energy will continue to increase, and Illinois will see a continued rapid growth of alternative energy production from "peaker" plants to wind farms and biofuels. These may have unintended consequences for wildlife. For example, wind generators, as currently designed, kill many birds and bats (4). Biofuel production, depending on which currently competing methods prevail, may lead either to conversion of conservation lands back to croplands or to conversion of croplands to diverse prairie-like habitats.

Water—Demands for both surface and subsurface water supplies will increase as a result of both population growth and increased energy production. Meeting minimum flow requirements for aquatic life in streams and rivers may become a significant issue, particularly during times of drought. Ground water, aside from its use as a source for drinking water (Fig. 19.2), also helps to maintain continuous flows at temperatures tolerable to native aquatic organisms, as well as to compensate for evaporation and drainage from important wetlands. At the same time, transportation demands on the large rivers will increase, possibly leading to greater control of flow through the lock and dam system. Together with pressure for increased flood control, the big rivers may become much more managed in ways that are largely incompatible with maintaining a healthy ecosystem.

Invasive species—The biological and economic impacts of invasive species such as Emerald Ash Borer, Gypsy Moth, Bighead and Silver Carp, Zebra Mussel, Purple Loosestrife, Garlic Mustard, and Reed Canary Grass (Fig. 19.3), to name but a few, have already been very significant (see Chapter 12). Similarly, introduced diseases like West Nile Virus and Soybean Rust have affected wildlife, domestic animals, crops, and humans. Invasive species almost certainly will grow in importance as humans and their goods and services move around the globe to a much greater extent and at a faster pace than in the past, leading to more rapid introductions of exotic invasive plants, animals, and diseases than ever before. There is also the risk of "bio-vandalism," the deliberate introduction of human, wildlife, or crop pests or pathogens as a tool of social aggression.

Climate change—Global climate change may be the most significant conservation issue. Rapid climatic changes over the last couple of decades have been well documented, and the only significant arguments concern the relative impacts of human activities on global climate and how to mitigate these impacts.

Interactions among threats—These trends will not act in isolation. Instead, they will combine to significantly increase threats to the environment. Extremes in droughts, floods and temperatures brought about by climate change will put added stress on natural communities, but increased fragmentation will make it more difficult for species to move to more favorable habitats. Community stability will be disrupted by local extinctions, especially of species that require larger habitats to carry out their life cycles. Loss of stability may in turn increase the potential for exotic species to invade and become established. The combination of these issues will require greater habitat management.

POTENTIAL IMPROVEMENTS

Habitat restoration—While the changes described above and documented throughout this book will continue to have an adverse affect on natural resources, there are also some promising positive trends. The first of these is increased investment in restoring native ecosystems, including streams and rivers, lakes, wetlands, savannas, prairies, and forests (see Chapters 14 and 18). This is an extremely challenging research arena for ecologists as they attempt to restore basic

Figure 19.1. Wild animals in our midst is an increasingly common situation as urbanization expands into former wildlife habitat. Photo by C. Warwick.


Figure 19.2. Natural seeps such as the one above provide year-round water for indigenous plants under variable climatic conditions. Photo by M. Jeffords.


Figure 19.3. A thick stand of the invasive Reed Canary Grass that infests Illinois wetlands. Photo by M. Jeffords.

ecological processes, as well as a suite of species that can be maintained in these habitats. No one will again see the vast expanse of prairie dotted with forests and woodlands that once covered Illinois, but efforts are underway to bring back some of the components of that system. Restoration efforts are beginning also to focus on providing wildlife corridors that will connect and allow passage between restored habitats. Management will be necessary to maintain these systems, and developing the necessary knowledge of life histories, species interactions, and basic ecological processes in a human dominated landscape will keep ecologists challenged for the next century.

Species restoration—A second positive trend is restoration of individual species, which is also documented throughout the various chapters of this book. Notable success stories typically involve game wildlife such as White-tailed Deer and Wild Turkey, although others involve charismatic non-game species like the Bald Eagle. Emphasis is shifting toward restoring other non-game species such as mussels, small fishes, amphibians, and plants as the public accepts the role such groups have in healthy and productive ecosystems.

Regional conservation planning. Throughout most of the twentieth century, conservation efforts, whether for habitats or species, were mostly local in scope and reactive in function. More recently, emphasis has begun to shift toward proactive, regional efforts. Rather than looking at species or habitats in isolation, often when they are on the verge of disappearing, these conservation plans address the full spectrum of habitats and species within a region in an effort establish protection and management that maintain healthy systems. Both the federal Endangered Species Act and federal support of state wildlife action plans have encouraged this positive trend. Table 19.2 lists the animal species the Illinois Department of Natural Resources has identified as being of conservation concern through its wildlife action plan. It is generally agreed that regional conservation planning saves money by conserving wildlife and vital habitat before they become rare and thus more costly to protect or restore. The Illinois Wildlife Action Plan (5), for example, identified 638 animal species in need of conservation, in contrast to the 144 animal species already listed as threatened or endangered. At the same time, regional conservation planning regulates human activities such as development in more predictable ways, thereby gaining more public and political acceptance of conservation.

CHANGES IN NATURAL RESOURCE CONSERVATION CONSTITUENCIES

Natural resource agencies will continue to face an ongoing conflict: how to provide recreational opportunities and greater access to sites for a growing human population while at the same time protecting natural habitats and native species. Historically, the primary constituents for natural resource agencies have been hunters and anglers, and sale of licenses and taxes on the equipment they buy provided major support for natural resource agencies and their conservation efforts. Yet the number of people fishing and hunting has been decreasing, as has the funding they provide (6).

While hunting and fishing appear to be declining, participation in other outdoor recreation activities is increasing. Some of these, such as horseback riding, all-terrain vehicle use, dog trials, and snowmobiling, have well-organized constituencies that press demands to pursue these activities on public lands. In contrast, the most rapidly growing area of outdoor use is observing wildlife and natural habitats, including pursuits such as bird watching (Fig. 19.4), hiking, camping, and other non-consumptive uses of natural resources. Despite their numbers, those participating in these activities generally are not as well organized or as politically influential. The full range of outdoor activities is not simultaneously compatible and conflicts among constituent groups are increasingly common. Furthermore, all may result in conflicts with conservation. Natural resource agencies will be pressured to resolve these conflicts and to develop new revenue sources (for example taxes on sporting goods and park entrance fees) that can support habitat acquisition and management.

One promising trend suggests that the public, and therefore policy makers, increasingly appreciates and

values biodiversity. Access to natural areas is being seen as a "quality of life" issue, necessary along with infrastructure and cultural resources for economic development. Many cities, including those in the Chicago metropolitan area, mandate that biodiversity be considered as part of regional planning. At a more basic level, Richard Louv and others have raised public awareness of children's need to be outdoors and experience nature (Fig. 19.5) to prevent what Louv has called "nature deficit disorder" (7). This groundswell of support for conservation bodes well for the future of natural resource agencies and organizations.

Figure 19.4. Bird watching is a popular outdoor recreation that is healthy and educational for humans and has little or no negative impacts on the environment. Photo by M. Jeffords

Figure 19.5. Outdoor experiences for young people provide enjoyable educational opportunities to foster appreciation of nature throughout the state. Photo courtesy of the Chicago Park Distict.

THE ROLE OF RESEARCH AND NEW TECHNOLOGIES IN THE FUTURE OF NATURAL RESOURCE CONSERVATION

The H. John Heinz III Center for Science, Economics and the Environment reported that "to manage wildlife and their habitats more effectively, conservationists and wildlife professionals need better information about wildlife populations and key threats and stressors that affect wildlife." (8) They called for better monitoring data, including the collection of information on wildlife status and trends, and on the number and distribution of non-native species and their effects on wildlife and ecosystems. The Heinz Center report reflects the growing recognition that effective natural resource conservation depends on solid scientific data and analysis.

Some of the conservation questions scientists are being asked to address have remained unchanged for more than a century: How abundant is a given species (Fig. 19.6), where is it found, and how are its numbers and distribution changing over time? Other questions are newer and evolving. Examples include examining the effectiveness of management approaches on the full range of species in an area, understanding underlying ecological processes in relation to habitat restoration, and predicting the biological effects of climate change. This last issue has, in turn, spurred scientists to re-examine long-held conclusions about such issues as design of nature preserves, genetic sources for restoration material, and "assisted migration" (intentionally moving species into areas where they are not native but that will become suitable habitat under reasonable climate change models).

The next 50 years will also see significant advances in scientific technology, many of which will prove extremely valuable for conservation research. Scientific technologies are now changing so rapidly that it is difficult to predict new developments even 10 years into the future, much less 50 years. Some trends already underway are certain to continue, however. A few of these are briefly described below.

Figure 19.6. Studying species like these Monarch butterflies helps researchers understand how the abundance and distribution of populations change across time. Photo by M. Jeffords.

Table 19.2. Predicted trends for INHS 2008-2058: Evolution of scientific services provided by INHS.

In the future, INHS research and scientific services will increasingly:

1. fuel the information requirements for adaptive and ecosystem-based resource management, particularly the effectiveness of conservation, rehabilitation, restoration, and management approaches

2. integrate across multiple scales spatially (local to regional) and temporally (snapshot to long-term trends), as well as within more global contexts (e.g., human influence on oceanic processes)

3. integrate across multiple biological levels from genes to landscapes, simultaneously taking a reductionist and holistic view of the nature of Illinois

4. span the full breadth of the "basic to applied" continuum of research and technology transfer
5. focus on ecological function as well as taxonomic and community composition

6. investigate questions that are quantitative, interdisciplinary, and "synthetic" in approach

7. focus on exurban and agricultural landscapes for their potential contributions to ecosystem function as well as ecological processes occurring at the exurban-agricultural-wildlands interface

8. focus on how emerging energy sources and water uses impact ecosystem health and services

9. integrate human dimensions of ecological health - sociological, political, economic, education, and engagement

10. explore the form and function of non-traditional elements of biological diversity, such as microbial communities and pathogens

11. emphasize and address the scientific underpinnings and consequences of E.O. Wilson's "Four Mindless Horsemen of the Apocalypse" (9): invasive species, habitat loss, over-exploitation, and pollution

12. communicate research outcomes beyond the Survey's traditional audiences to others including urban and suburban population centers, land-use and transportation industries, NGOs and public service institutions, policy-makers, and the general public.

EMERGING ROLE OF MOLECULAR GENETICS

Tools derived from molecular biology are revolutionizing other areas of the biological sciences, including conservation science. In the past, patterns of genetic relatedness were inferred indirectly from morphology or various chemical end products, whereas these patterns can now be determined directly from the DNA of organisms. DNA sequence data will be applied to a variety of natural history and conservation questions to:

- resolve longstanding controversies about how various groups are related to each other and clarify how they should be classified
- show how current distributions reflect historical changes in climate and geography (Fig. 19.7)
- allow rapid identification of species from their genetic "bar code"
- facilitate detection of endangered or invasive species
- promote identification of disease-causing organisms
- expedite biological inventories
- create DNA fingerprints for tracking ecological and behavioral processes
- measure genetic exchange among populations, aiding the design of effective and efficient conservation reserve complexes

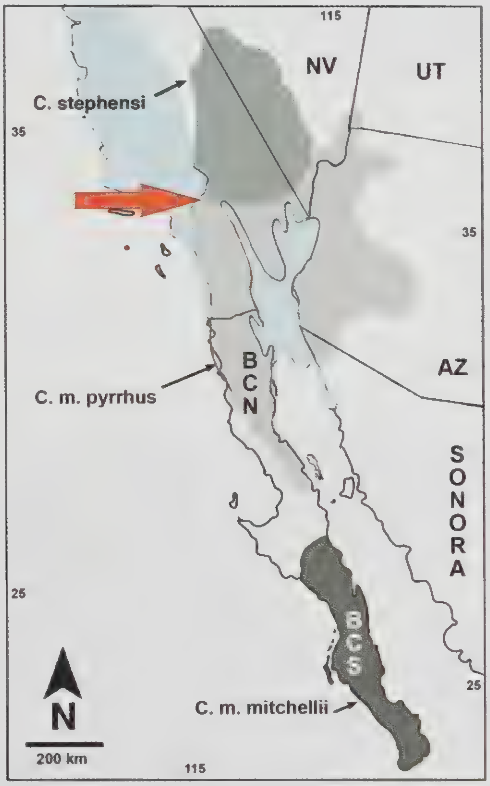

Figure 19.7. Recent analysis of DNA revealed the presence of a new species of rattlesnake, *Crotalus stephensi*. This species likely arose when higher sea levels (shown in blue) in the southwestern United States during the Pliocene (3.6–1.8 million years ago) restricted gene flow (area indicated by red arrow) between northern and southern parts of the ancestral population and speciation occurred. Modified from (11).

NEW TECHNOLOGIES FOR MONITORING ANIMAL BEHAVIOR

The behavior of animals in the wild is inherently difficult to study, yet a sound knowledge of animal behavior is essential to understanding their ecology and, therefore, their conservation and management. Advances in automated radio telemetry are allowing biologists to collect comprehensive movement, audio, and energy consumption (i.e., heart rate) data in a variety of species. Stationary acoustic microphone arrays (Fig. 19.8) allow real-time tracking of many animals simultaneously in both terrestrial and aquatic environments. Coupled with sophisticated statistical analyses conducted using high-speed computers, these technologies will allow researchers unprecedented insight into how animals utilize their environment and interact with each other throughout the entire day and night.

IMPROVED INVENTORY TECHNIQUES

Increasingly sophisticated remote sensing, digital imaging, and GPS-based mapping technologies, together with other new technologies such as those described above and all linked through Geographic Information Systems (GIS), will facilitate inventories of natural community distributions and health, and thereby foster increased long-term monitoring.

The INHS and other institutions have conducted repeated inventories that in some cases extend back more than 100 years. Integrating these data sets, both with each other and with newly gathered data, has been difficult because of changing techniques. Recent improvements in statistical modeling, made possible by high speed computers, allow more robust comparisons among disparate data sets. As more and more data can be brought together to understand changes over time and thus predict future changes, support for further monitoring should increase.

DATA MANAGEMENT AND ACCESSIBILITY

Scientific institutions, including the INHS, have amassed extensive data sets that include scientific collections, GIS mapping, inventories, and long-term monitoring. New

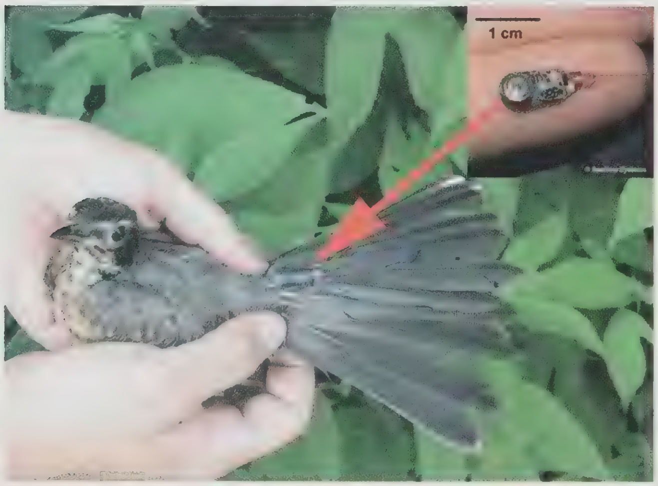

Figure 19.8. In addition to providing information on location, small (<1 gram) radio transmitters such as shown here, are now providing researchers with data on vocal activity and heart rate. Photo by T. Beveroth.

technologies like those described above are also generating vast quantities of data. Although some of these historical data have been captured in computerized data sets and most new data are computerized in real time, the future holds exciting prospects for rapid data capture, increased integration of diverse data sets, and improved accessibility. Digital image analysis and semantic processing promise to speed data capture from specimen labels and hard-copy files. Automated methods for parsing verbal location descriptions and then using computer algorithms to generate digital geographical coordinates will allow data from various sources to be linked spatially. Adoption of data exchange standards and development of Internet portals will allow users to visit one location and access data from many institutions. Within the near future, anyone with Internet access will be able to integrate millions of ecological, climatological, geographical, genetic, and biodiversity data elements. This will greatly facilitate existing ecological and evolutionary research. It will also significantly enhance the ability to carry out predictive modeling of processes like the biological impacts of global climate change and the spread of invasive species. The educational potential of this expanding data access is only beginning to be explored. The proliferation of molecular tools and the availability of extensive and integrated data promise to revolutionize biological research and outreach.

PREDICTED TRENDS FOR INHS AND OTHER RESOURCE AGENCIES 2008–2058

The predicted changes in the landscape, in natural resource management, and in conservation science summarized above will require that the INHS evolve in ways that could serve as a model for other agencies. Some responses will be reactionary and depend on specific circumstances. Most, however, should reflect anticipation of these changes so that the Survey's science continues to meet the needs of its state and federal partners that have mandates to conserve, manage, preserve, or regulate wildlife and the habitats upon which they rely.

Some major trends that can be predicted for the evolution of the scientific enterprise at the INHS are listed in Table 19.2. Several of these trends involve integration of diverse fields and scales of focus. For example, associated with the nationwide movement toward more proactive and regional approaches to natural resource management will be an enhanced need for information about the biology, human dimensions, and even economics of the resources. As the Survey transforms to meet future needs, it will continue to conduct relevant research that addresses key uncertainties, undertake monitoring to assess specific conservation and management actions, and evaluate broader program goals and objectives.

To address the changing landscape and conservation needs, the Survey's approaches will likely continue to broaden to include examination of questions across multiple scales, both spatially (local to regional) and temporally (snapshots to long-term trends), as well as placing these findings within broader global contexts (e.g., human

influence on oceanic processes). While state boundaries are convenient for political and jurisdictional efficiency, biotic systems operate at a watershed, biome, or much larger scales. Related to this, greater emphasis will be placed on scientific efforts that integrate disciplines as different as biophysics, economics, social science, and basic ecology.

Perhaps a more difficult challenge will be in the way the Survey transitions from more "form" related aspects of biological diversity (such as composition and structure of variation) to more "function" related aspects (such as the processes behind variation). Here, the future will lead to a refreshed sense of urgency and acuity in INHS's work, recognizing that while it is not possible to turn back the clock to more pristine versions of Illinois' landscape and plant and animal assemblages, it is essential simply to keep the clock working. Re-establishing vital ecological processes in highly modified human dominated systems will be a major challenge for biologists in the future (Fig. 19.9). The good news is that as the value of ecosystem services and natural resources becomes better quantified, these data will play a greater role in land use decision making and planning at a local, regional and national level.

At the same time that the scientific endeavor at INHS continues to adjust to meet changing needs, it will face changes in its scientific staff. Like all American institutions, the Survey will face a massive loss of experienced staff as the large number of baby-boomers retires. At least currently, fewer students are being trained in field-oriented biology than there are anticipated positions. Competition for talented scientists will be intense, but will also promote an increasingly diverse workforce that will be better able to reach out to under-served and under-represented, largely urban constituencies. These changes will help the Survey remain relevant as Illinois' population changes.

Figure 19.10. Restoration of natural systems and human land use are not mutually exclusive activities. With proper management, based upon state-of-the-art science, both can coexist for the benefit of the natural world as well as our society. Photo by M. Jeffords.

CONCLUSIONS

Ultimately, the challenge facing humans is "sustainability." Although this has been defined in myriad ways, The World Commission on Environment and Development (also known as the Brundtland Commission) articulated what has become a widely accepted definition of sustainability: "[to meet] the needs of the present without compromising the ability of future generations to meet their own needs." (Fig. 19.10; [9]). Achieving sustainability requires not only the will to use resources wisely, but also information about those natural resources and how human actions affect them. In July 2008, the Illinois Natural History Survey, together with the other state surveys, entered the University of Illinois as the Institute of Natural Resource Sustainability. This new structure recognizes INHS' longstanding role in providing information necessary to attain sustainability and positions it to respond to changes in conservation science as an independent research organization.

As the Survey approaches its two-hundredth anniversary in 2058, the INHS will remain a primary force in gathering, analyzing, and disseminating scientific information to managers, decision-makers, and the public. By continuing to build trust with the citizens of Illinois it will continue to serve the two vital roles implied in the title of this book— "canaries in a coal mine" and observers in the "catbird seat."

Figure 19.9. Canada Geese thrive at the Emiquon National Wildlife Refuge on the Illinois River. The refuge is an example of the successful restoration of a large river floodplain that had once been drained and altered for cropland. Photo by M. Jeffords.

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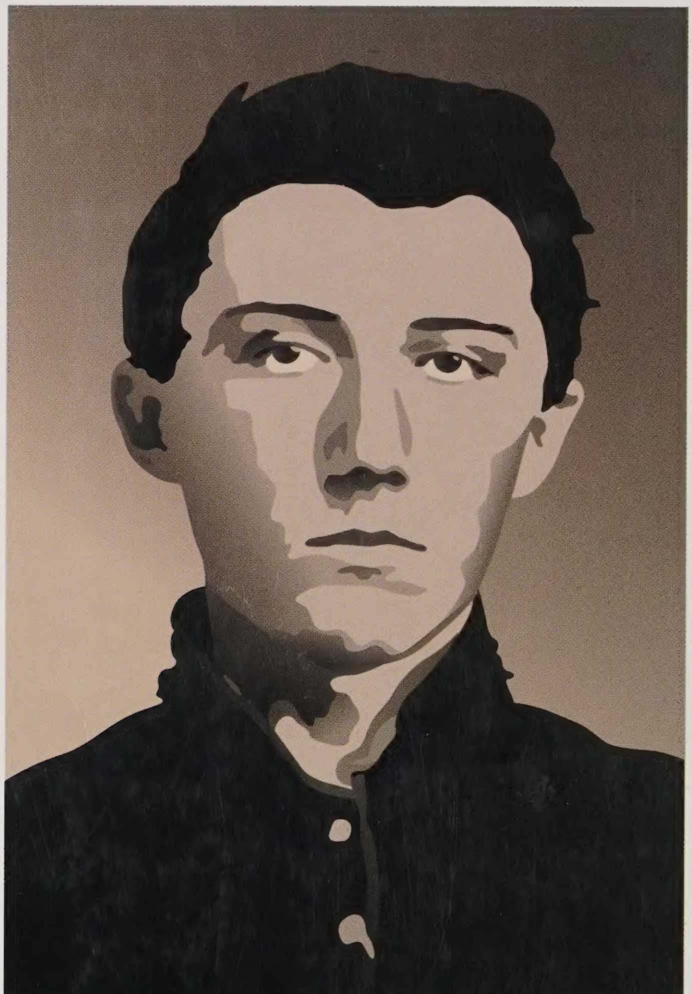

"The first, indispensable requisite is a thorough knowledge of the natural order—an intelligently conducted natural history survey. Without the general knowledge which such a survey would give us, all our measures must be empirical, temporary, uncertain, and often dangerous."

Stephen A. Forbes, 1880
Founder of the Illinois Natural History Survey

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